ASPECTS OF THE TEMPORAL PATTERN OF DRY SEASON FIRES IN THE DRY DIPTEROCARP FORESTS OF THAILAND

Saranarat Kanjanavanit

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DEPARTMENT OF GEOGRAPHY,

SCHOOL OF ORIENTAL AND AFRICAN STUDIES,

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ABSTRACT

This thesis reviews the role of fire, and especially its seasonal timing, in the moist savanna forests of mainland Southeast Asia, and, in particular, of Thailand. Based on one year's experimental field work carried out in Uthai-thani Province, West Thailand, the thesis investigates the development of conditions for burning and fire behaviour throughout the dry season. Spatial patterns of fire temperature and the duration of maximum temperature are measured, along with a wide range of other key variables, such as fireline intensity and speed of fire spread. The climatic preparation of fuels for ignition is also examined.

It is argued that fire is endemic in this formation, although its character has changed much over time. Conditions for burning were found to be optimal in March (the late dry season), when fire occurrence and behaviour measurements were at their peak. Two ground cover fuel-fire regimes are recognized: 1) heterogeneous ground cover, with a high proportion of non-grass species, producing patchy, low temperature burns ($\leqslant 650°$ C), except where conditions are very favourable, as in the late dry season; 2) homogeneous grass cover, notably of *Heteropogon triticeus* (R.Br.) Stapf.ex Craib, which tends to burn evenly, and extensively, with a high temperature (750-900° C) and speed of spread (0.6-3.0 cm s^{-1}), when the grass stalks have collapsed after the arrival of the Northeast monsoon (early February - mid dry season). As in African moist savannas, short-term recovery shows a tendency for low temperature burns on partially dry grass to favour woody species, while discouraging grass growth.

It is suggested that fire timing and placement can be used as an effective tool in ecological management, to: 1) prevent the extensive occurrence of destructive wildfires; 2) meet a range of different planning objectives. It is further argued that, since the fire ecology is local, the management pattern must also be devised locally. A change from central state control of policy is thus proposed.

Key Words: fire ecology, fire timing, phenology, fire management, savanna forest, Thailand, Southeast Asia.

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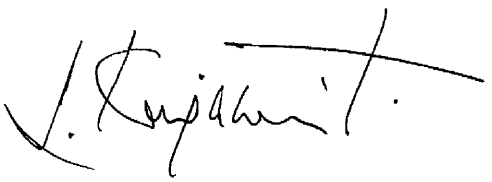
Finally, I would like to give my sincerest thanks to my father, Dr.Rachot Kanjanavanit, for all his financial support during my years of study in England; without his support none of my work would have been possible.



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CHAPTER 1.

THE ROLE OF FIRE IN SAVANNAS

"The (savanna) forest changes with the seasons. At times it gets dense and untidy, and at times it gets trimmed (by fire). It sleeps, then it awakes. The forest is not dead all the time."

A Karen villager of Ban Klong Salao,
Uthai-thani province, West Thailand.
(pers.comm., December 1987)

1.1 Introduction

Although present evidence is not sufficient to determine precisely when terrestrial fire first occurred, wildfire is likely to have been a common phenomenon ever since the early build-up of land plant biomass some 350-400 million years ago (Komarek 1968, Harris 1972, Gillon 1983, Patterson & Backman 1988, Schüle 1990). Fire has thus played an integral part in the shaping of terrestrial ecosystems, and there is hardly a vegetation type in which fire has not had an influence.

Even parts of the moist lowland tropical evergreen rain forest, which was once thought to have evolved steadily without disturbances (e.g. Ashton 1969), is now known to burn, albeit with low frequency, particularly when rare climatic events trigger favourable conditions for fire ignition and spread. This has recently been seen in Indonesia when the El Niño Southern Oscillation, a phenomenon caused by an irregular warming of the usually cool surface of the eastern equatorial Pacific ocean (Whitmore 1990), induced prolonged drought in 1982-83, 1986 and 1991. The burning was made particularly drastic through poor human management of extensive swiddens and logging operations, which created large areas of secondary forest and produced high fuel loads. Certain special conditions can also induce fire in tropical rain forest, such as the presence of extensive underground coal seams in East Kalimantan, which have continued to smoulder since their first ignition in 1983 and 1986 (Poole 1991).

Fire burns when there are sufficient relative amounts of heat, oxygen and fuel. The inter-dependent relationship of these three factors to produce combustion is commonly known as the 'triangle of fire' (e.g. Hirst, date unknown; Fig.1.1). In the case of forest fuel, the solid surface is usually converted by heat radiation into gases, which then react with oxygen to produce flame. When all the volatiles are burned, the solid is left as charcoal, which glows as its surface is hot enough to

react directly with oxygen. The reaction can continue as long as adequate heat is available for fresh fuel and oxygen to become sufficiently hot.

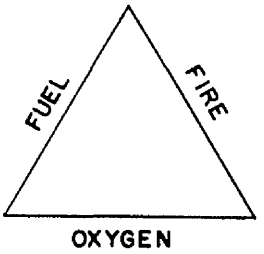

Figure 1.1. The fire triangle.

Climate, therefore, controls fire in several ways. First, temperature and precipitation largely determine the productivity of vegetation, and hence the amount of potential fuel available. Secondly, climate regulates the moisture content of this fuel, which in turn controls its **ignitability**[1] and the **sustainability** of the burn. Finally, climate influences independently the conditions for ignition and the spread of fire, there being a minimum temperature and maximum relative humidity that can support burns in various habitats.

Within this overall climatic control, however, fire may itself influence the vegetation as a control on future fuel characteristics. One fire will influence the next fire, and so on. Thus, while vegetation productivity, fuel burning properties, and the distribution of fuel together determine particular fire characteristics, the spatial pattern of fire, its frequency and **intensity**, equally combine to create a fire regime which plays a distinct role in the re-creation of the vegetation formation after fire. These basic principles concerning the ecological role of fire will be established in this introductory chapter, before embarking on a discussion of the role of fire in savanna ecosystems, in particular a study of the significance of the seasonal timing of fire. This is the main context for the work discussed in the present thesis.

1.2 The ecological significance of fire

The main principles of general fire ecology have already been well summarized by Chandler *et al* (1983), among others (e.g. Davis 1959, Kozlowski & Ahlgren 1974, Wright & Bailey 1982). It can be said, briefly, that, in any given ecosystem, fire acts chiefly as a selective agent, a consumer and a decomposer. Over the course of plant evolution, recurring

[1] Terms appearing in bold are defined in Glossary (p.265).

fire has selected species with adaptive traits that enable them to succeed after fire. These traits are not necessarily adaptations specifically for **fire regimes**, but are more likely to be adaptations to a number of disturbances and constraints which a plant faces in its environment, notably drought, which itself induces conditions for fire, and which imposes similar stresses on living plant tissue. A plant may be adapted to fire physiognomically (morphologically), physiologically, or phenologically, or any combination of these three.

A range of survival strategies appear to depend on the number of fire events an individual plant is expected to experience within its life cycle (Chandler *et al* 1983). If fire occurs once, it is only important to ensure successful reproduction of the species, death of the parent being of no consequence. A good example is jack pine (*Pinus banksiana* Lamb [2]) with its serotineous cone[3]. On the other hand, some protective means to withstand fire is crucial if a plant is to survive recurring fire events throughout its life time. Thus, fire-tolerant trees and shrubs commonly have thick bark to insulate their cambium layers against lethal heat. Their buds are often protected in various ways, such as by being covered with dense layers of foliage, or by being buried deep within branch axils, or again by being located on the underground roots, which can sprout after the removal of above-ground parts. Similar strategies characterize the geophytes, in which perennating organs are protected underground in a dormant state during the drought and fire season. The effectiveness of soil as a heat insulator will depend largely on the depth and amount of organic matter content (Stott 1986).

Fire can further induce flowering, increase seed liberation, and stimulate seed germination. The timing of seed release in relation to a fire event is also important. For instance, it is advantageous for hard-cased seeds, or serotineous fruits, to drop before the fire, which cracks the seed case or melts the waxy coating to release seeds for germination (e.g. *Pinus banksiana*). In contrast, plants with susceptible seeds must drop them after fire and germinate quickly on the burned ground. Annual seeds, which are released at the end of the growing season, are often burned, unless they are buried underground before a fire occurrence.

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[2] The nomenclatural authority is given when a species name appears for the first time in the text, and in Appendix I (p.266).

[3] Cones sealed with wax preventing seeds from being released until the wax melts.

The spatial pattern of fire, its frequency, its intensity, and its timing, therefore, help to select a community of plants which are adapted to suit the overall fire regime of that particular habitat. For example, in the montane-boreal coniferous forest of the Daxinganling Mountain region in Northeastern China, short return interval fires of low-medium fireline intensity occurring early in stand succession, after it has been destroyed by severe fire or cutting, will favour a pure stand of birch and aspen, the domination of which are maintained until a long fire-free period allows for the development of coniferous species, such as larch, which generates under the canopy of the pioneer species. Subsequently, medium-return interval fires will maintain a mixed stand by creating gaps that do not allow birch and aspen to be out-competed by larch (Goldammer & Xueying Di 1990). Fire characteristics then vary with component species. For instance, where crown fires tend to occur mostly on coniferous trees, it is a rare phenomenon in forest stands dominated by broad-leaved hard woods, as seen in North American temperate forests (Chandler *et al* 1983). This is a good example of how vegetation influences fire characteristics.

Fire can thus change vegetation structures or maintain them, depending on the overall adaptive nature of the formation to a particular fire regime. In the case where mature trees and tall shrubs are well-adapted to withstand fire, a key variable in the structural dynamic will be the survival of seedlings. This is a stage in plant life when plants are particularly susceptible to fire, and it is common for fire-prone plants to bear and germinate large quantities of seeds which increases their chances of survival, the rate of which depends significantly on the fire intensity and the patchiness of the burn. Above all, it depends on fire frequency and on the nature of the fire-free interval, which allows seedlings to mature. When the number of seedlings surviving is in equilibrium with the number of mature plants being displaced, overall community physiognomy will be maintained. However, in many edaphically determined formations, fire exclusion may not lead to changes in vegetation structure, as is seen in many savanna communities (e.g. Barrington 1931, Belsky 1990).

As fire consumes, it reduces organic plant biomass into available nutrients in the form of ash, high in basic ions, which tends to raise the pH value of acid soils. Some proportions of calcium, potassium and magnesium are transported away as fine particles, while nitrogen, phosphorus and sulphur are lost as gases to the atmosphere. Fire also has effects on the physical properties of soils, particularly where

there is a high percentage of clay particles which may fuse to become more compact and less porous. The extent of soil physical and chemical conversion depends on the intensity and temperature of fire.

Giovannini *et al* (1990) experimented on the effect of heating on the quality of some Italian soils, and found that solubility of various cations beneficial to plant growth is promoted by low temperatures of <220° C. The combustion of soil organic matter takes place between 220-460° C, while temperatures of >460°C causes damage to the crystallographic and spatial structure of soil mineral parts. Unlike organic matter content which can be replenished, soil structure, once changed, cannot be restored.

However, it is possible that unless soils contain a high amount of organic matter or clay particles, a burn, on the whole, probably does not alter too significantly the chemical and physical properties of the soil. If erosion is not taken into account, a burn on sandy soils, poor in organic matter, tends to redistribute nutrients in an ecosystem to the surface and the upper soil layer, rather than decreasing them, provided that most of the soluble nutrients are taken up by plants before they are lost through leaching. So, in the long run, soil status is generally maintained. However, the effects of burns on soil properties and nutrient cycling will vary markedly from site to site, and between different elements, depending on such factors as fire intensity, soil characteristics and topography, soil micro-organisms, the amount and timing of precipitation received after fire, how soon recovery takes place, and the rate and efficiency of plants exploiting the nutrients released.

When vegetation burns, it further emits greenhouse gases, like carbon dioxide (CO_2), methane (CH_4) and di-nitrogen oxide (N_2O). Although the current extent of the wildfire contribution towards the so-called 'greenhouse' effect is as yet unclear, it is likely to be significant (Newell *et al* 1989, Wei Min Hao *et al* 1990). This brings the interaction between climate, fuel and fire to a closed triangle. Fire, however, influences climatic change in more than one way. At the local level, the change in vegetation structure and the blackened colour of burned ground (the albedo) have direct effects on the micro-climate.

The extent of the significance of fire thus varies in different ecosystems. Table 1.1 presents a range of fire regimes in some of the world's major vegetation types, including the tropical savannas.

1.3 Fire and savannas

1.3.1 Savannas defined

The term 'savanna' has been a cause of much dispute and confusion (e.g. Bourlière & Hadley 1983, Huntley & Walker 1982). Originating from the language of the Arawak Indians of the Greater Antilles islands in the Caribbean (Blydenstein 1969, Harris 1980), where it is used to describe 'land without trees, but with much grass, short, and tall' (Oviedo y Valdes 1535, cited after Bourlière 1983), the term has since been applied to a wide range of vegetation types from near closed forests to near deserts, from within the tropics to all global climatic zones.

Sarmiento (1984) has divided the different uses of the term

ECOSYSTEM	FIRE FREQUENCY (years)	FIRE TYPE
Tundra	rare	Surface fire
Taiga & boreal forests 1. moist 2. dry	 200-250 40-65	From underground to crown burns
Temperate forests (North America) 1. northern limit 2. southern limit	 10-25 2-5	Surface fire; crown burns are rare*, but recently more common.
Mediterranean shrubland	15-100	'Bush' crown fire
Temperate grasslands 1. steppe (Mongolia) 2. prairies(N.America)	 annual 1-6	Surface fire
Tropical savannas 1. moist 2. dry	 1-2 10-50	Surface fire; crown burns are rare.
Semi-deserts & Deserts	rare	Surface fire
Tropical rain forests	rare	From underground to crown burns

* usually occurs on coniferous trees

Sources

1. Lacey et al (1982)
2. Chandler et al (1983)

Table 1.1. Fire type and frequency in some world ecosystems.

'savanna' into four groups: 1) open formations dominated by grasses, in the lowland tropics, where trees and shrubs, if present, are of little physiognomic significance (e.g. Drude 1890, cited after Bourlière 1983; Beard 1953, Whittaker 1975); 2) mixed tropical formations of grasses and woody plants, excluding pure grasslands (e.g. Walter 1973); 3) mixed formations in any geographical area (e.g. Dansereau 1957, Schimper 1898, 1903); and, 4) any formation within the region experiencing a winter dry season and summer rains (e.g. Jaeger 1945, Troll 1950, Lauer 1952, all cited after Sarmiento 1984).

Given such confusion, some writers have rejected the use of the term outside its continent of origin (Pratt *et al* 1966), while others have decided to adopt it as a climatic term, rather than a vegetation designation, to describe the 'Intermediate Tropical Zone' with definite wet and dry seasons, naming this the 'Savanna Region' (Harris 1980), thereby adding further confusion to the whole issue. Being, however, "a useful (term) in that it groups different types of tropical vegetation which share a number of structural and functional characteristics" (Bourlière & Hadley 1983:2), and one which is perhaps too well embedded in general usage to delete, an increasing number of authorities have come to an agreement to adopt the term 'savanna' for those tropical and subtropical ecosystems, which lie between rain forest and deserts and semi-deserts, with a more or less continuous C^4 photosynthethic grass stratum that is either treeless, or studded by trees and shrubs of variable height and density, and where growth patterns are closely associated with alternating wet and dry seasons, fire normally being a prominent feature. Within this broad definition, many writers have recognized a whole range of classification types for each continent, usually based on physiognomy and floristic composition, and ranging from savanna woodland to grass savanna (Harris 1980), or even to 'thicket and scrub' (Cole 1986).

Areas where savanna vegetation is found lie within Köppen's (1918, after Mizukoshi 1971) *Aw* (savanna) and *Am* (monsoon) climatic zones, largely between the latitudes of Cancer and Capricorn (Fig.1.2). Such areas receive an annual precipitation of 250-2000 mm, most of which falls in the wet season months. This is similar to temperate grasslands, where a large proportion of the 250-1000 mm annual rain falls in the spring and early summer (Chandler *et al* 1983). Dry seasons in savannas range from 2.5-10 months a year. What differentiates a savanna from grasslands of other biomes, however, is the higher light intensity and temperature which is warm throughout the year and which rarely falls low enough to check

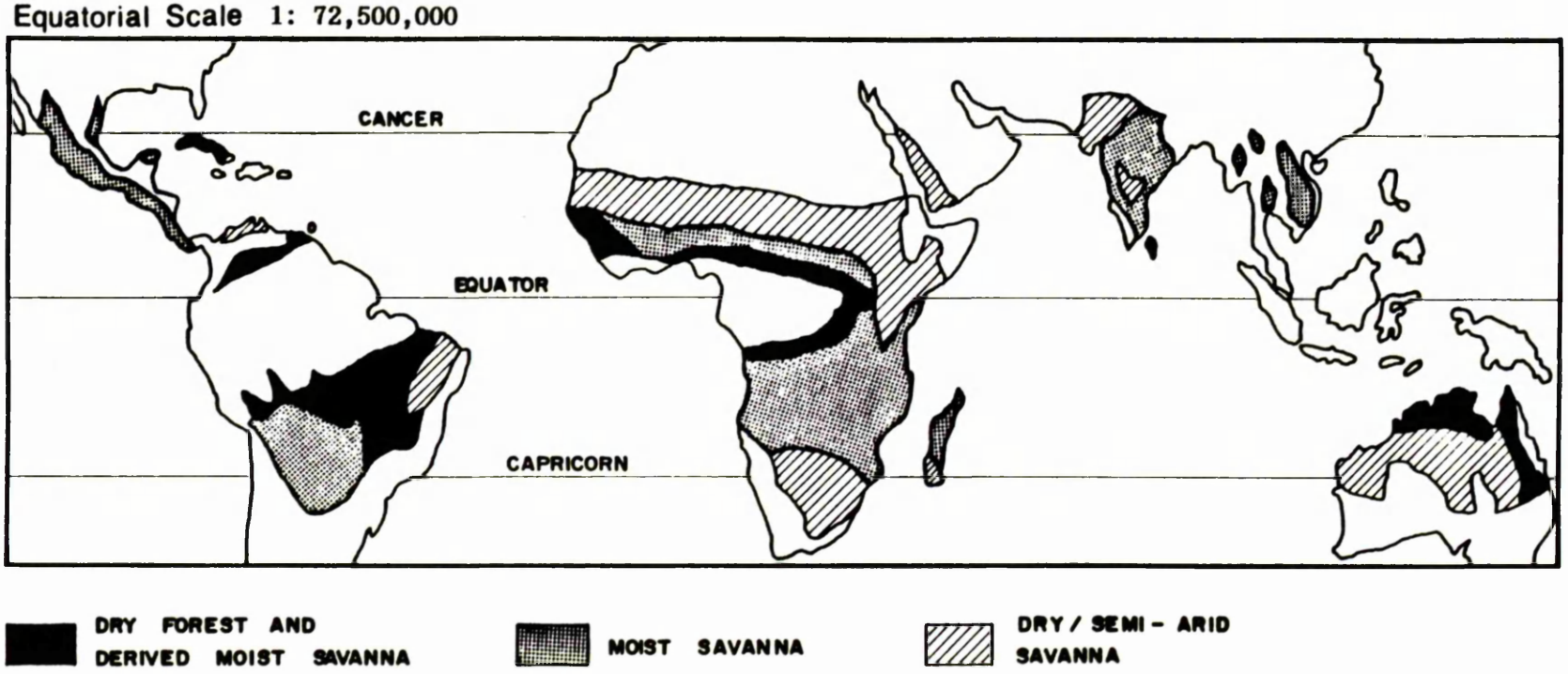

Figure 1.2. World map of tropical savannas (modified after Deshmukh 1986, Fig.8.1: 224).

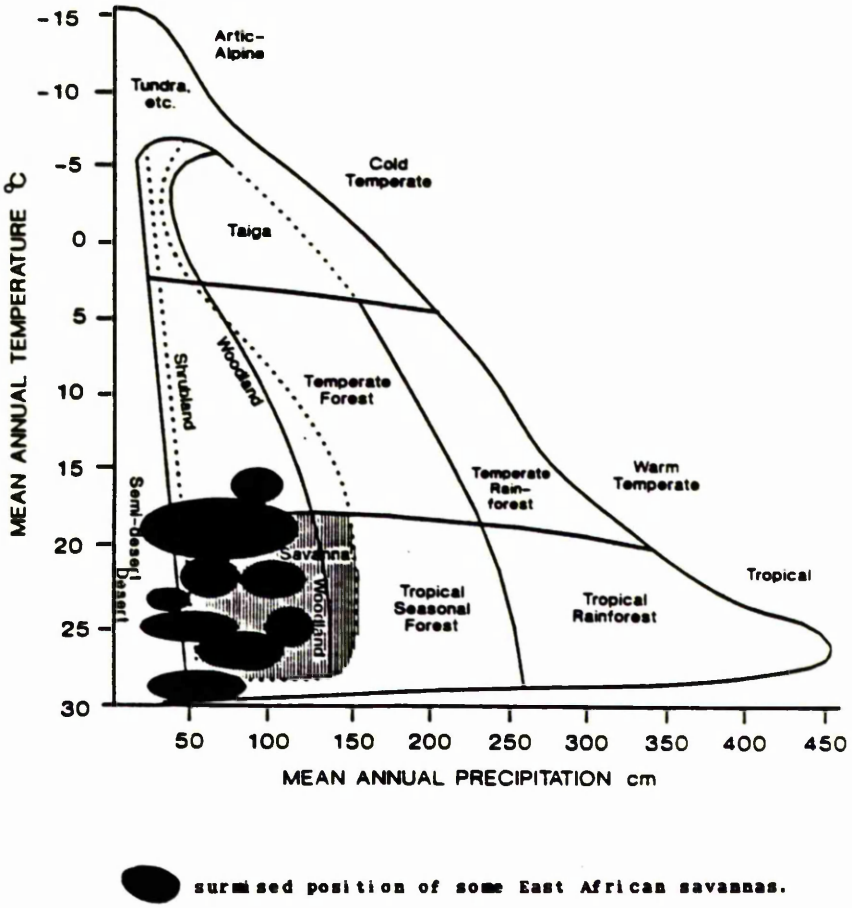

Figure 1.3. The distribution of East African savannas in relation to Whittaker's (1975) model of World vegetation, based on precipitation and temperature variations (taken from Belsky 1991).

plant growth, except in a few localities, such as South-Central Africa, where frost is a common occurrence.

C^4 grass-dominated savanna is especially adapted to maximize productivity under hot and dry conditions with high light intensity, where carbon dioxide, rather than light and temperature, becomes a limiting factor in photosynthesis. Under such an environment, high leaf temperatures and stomatal closure normally lead to elevated O_2/CO_2 ratio on photosynthetic cells, which lowers the rate of photosynthesis through oxygenation competition with CO_2 fixation on leaves. But in C^4 plants, there is a special CO_2 concentrating mechanism which prevents oxidation,

and therefore it exhibits very little photorespiration[4]. C^4 plants can further make use of the maximum amount of available CO_2, havinglower compensation points[5] and higher rates of CO_2 fixation than C^3 plants. However, since a rise in CO_2 concentration in the atmosphere tends to increase the rate of photosynthesis in C^3 plants while having little impact on C^4 plants, the present day advantage of the latter in the tropical environment may reduce greatly with the advance of the 'greenhouse effect' (Woolhouse 1990). It will be extremely difficult to predict precisely what form savannas will take under such circumstances.

Belsky (1990) finds generally the climatic distribution of East African savannas to fit well within Whittaker's (1975) classification of world vegetation, based on physiognomy and biome variation that are modelled on the axes of mean annual precipitation and temperature (Fig.1.3). Towards the moister end of the climatic range, savanna formations share a distribution with tropical semi-evergreen forest or closed seasonal forests, but with semi-deserts at the dry end of the scale. The ecological determinants of savanna systems will be mentioned later. It should be noted here, however, that this is a near perfect fire climate, with enough moisture to support good herbaceous growth, and a dry period warm and long enough to dry it. Consequently, savanna is one of the most fire-prone of ecosystems, and one in which fire has always been an indigeneous force.

1.3.2 Fire as an indigenous force in savanna

Savannas evolved, along with other fire-prone ecosystems, in the Upper Tertiary and Quaternary from thick woody domination in the Paleocene (Schüle 1990). From Table 1.2, it can be seen that grass pollen and open vegetation already existed in the middle Eocene in Africa, South America and Australia. This then spread during the Miocene and Pliocene, at least in the latter two continents, long before the arrival of humans (van der Hammen 1983, Kershaw 1988, Burrows 1990). During these times, fire could only occur from natural causes, such as atmospheric lightning, volcanic eruptions, friction, and the rare events of spontaneous combustion. In South Africa, fire caused by falling boulders is not rare

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[4] Respiration that occurs in the light. In C^3 plants, the rate of CO_2 release by photorespiration can be 3-5 times greater than that of dark respiration.

[5] Minimum level of CO_2 concentration required to reach an equilibrium, where the photosynthetic uptake of CO_2 is exactly balanced by its respiratory release.

in some mountainous areas, such as Cedarberg Mountains, Western Cape, where it is responsible for about 5% of fire events (Edwards 1984). The occurrence of natural fire is thus often limited, both by chance and by the distribution of conditions suitable for a burn or suitable for an occurrence of natural fire events.

On the whole, lightning is the most common source of natural fire, and this has been reported to strike the land surface of the globe on average 100,000 times per day (Yi-fu Tuan 1971, after Goudie 1990). In the temperate regions, particularly North America, fires caused by lightning are common, forming 64% of wildfire events in the United States, which adds up to a mean of 4871 fires a year, each burning a mean of 38,287 acres (15,314.8 ha; Komarek 1968). The occurrence of lightning fire is usually limited to quite a short period of the year, sometimes within a few weeks, when there are dry thunder storms experienced over regions with combustible fuel. During such a period, the number of lightning-caused fires can be very concentrated. On 12 July 1940, as many as 325 fires were recorded in the United States (Komarek 1963b).

By contrast, in the tropics, the number of lightning fires is generally low, because thunderstorms are more often accompanied by heavy rain (Batchelder 1968), although as much as 8% of fires in Australia are estimated to be caused by lightning (Luke 1962), and in Etosha National Park, South Africa, lightning is claimed to have been responsible for some 54-73% of total fire occurrences during 1970-79 (Trollope 1984a), concentrating largely in the highlands above 1000 m.a.s.l.(Edwards 1984).

Braithwaite and Estberg (1985) have evaluated 40 years of meteorological data from Darwin, Northern Territory, Australia, and they found that the potential for lightning fire only occurs during the last three months of the eight months of the dry season, i.e. when the number of thunder days is high, but the average rainfall on a thunder day is low enough not to extinguish the burn. In Africa, the late dry season or the early rainy season are also characteristic periods of lightning fire occurrence (e.g. Trollope 1984a, Frost & Robertson 1987). It is possible, however, that the number and/or the area of lightning-caused fires may have been greater before the arrival of humans, when no extensive land was burned prior to the natural fire season.

Although these natural fire regimes would have varied through time, the most drastic changes came with first a hominid, and then a human presence in savannas. Evidence for an early hominid-fire-savanna relationship comes from around 1,5-2,000,000 years b.p., with indications in Africa of hominids staying near to slow-burning fires (Barbetti 1986,

PERIOD	EPOCH		EVENTS	YEAR, b.p.
Quaternary	Holocene		Rise of agriculture and civilizations	10,000
	Pleistocene		*Homo s.sapiens* in America	20,000
			H.sapiens in Australia	50,000
			H.sapiens (Eurasia)	200,000
			Homo erectus, the fire maker (Eurasia)	500,000
			Hominids staying near fire (Africa)	1,500,000
Tertiary	Neogene	Pliocene	Appearance of hominids (Africa)	2,500,000
		Miocene	Appearance of 'savanna'	12,000,000
	Paleogene	Oligocene		25,000,000
		Eocene: Upper	First grass pollen records	38,000,000
		Eocene: Middle		
		Eocene: Lower		50,000,000
		Paleocene		65,000,000

Sources

1. Coulter & Dittmer (1964: 292-293)
2. Johanson & Edey (1981)
3. van der Hammen (1983)
4. Kershaw (1988)
5. Burrows (1990)
6. Schüle (1990)

Table 1.2. Geological time chart relating savannas and human/hominid presence during the Cenozoic Era.

Brain & Sillen 1988). These hominids appear to have evolved in a terrain characterized by a savanna-gallery forest mosaic (Clark 1980). It is not certain when humans proper (*Homo* spp) began to learn how to make and to use fire. However, with the arrival of *Homo erectus* (Dubois) Mayr in tropical andsubtropical Eurasia at least 4-500,000 years b.p. (Schüle 1990), there probably began a shift from a natural to an anthropogenic fire regime, which was potentially more extensive in both space and time, and which might have spread the savannas and seasonal forests further from

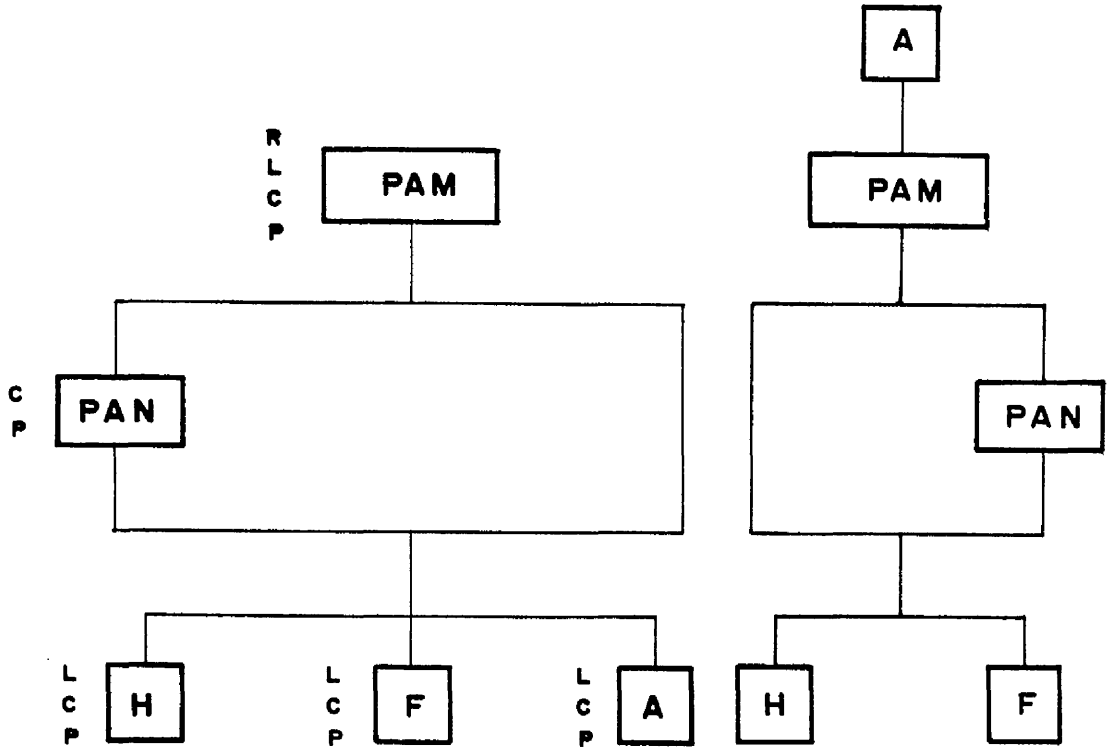
their original 'core' communities, but within the general savanna climatic limits.

Nevertheless, human-induced fire does not appear to have spread throughout all fire climatic regions of the world until *Homo sapiens sapiens* L. reached Australia and America some 50-40,000 and 20,000 years b.p. respectively (White & O'Connell 1979, Hammond 1980). Thus, anthropogenic fires in the tropics have developed from a matrix of non-agrarian cultures to agrarian economies, through Western colonization to contemporary fire regimes. A good example of such changes is provided by Braithwaite and Estberg's (1985) study in Northern Australia. Based on Haynes's (1984) detailed description of Aboriginal fire regimes and on their own data, they found that there were clear shifts in fire timing, particularly in the open forest, from lightning fires in the late burning season to Aboriginal fires in the early season, to contemporary fires that burn indiscriminately throughout, but which occur mainly in the mid-dry season. The ecological significance of such changes in fire regime will be discussed later.

1.3.3 Fire as an ecological factor in savannas

The interactions between the woody and grass components, the two main constituents of savanna, have been a major focus of interest in the modelling of savanna ecosystem processes. The pattern and distribution of these two elements forms an important basis for defining savanna characteristics, and thus of savanna classifications. The different forms of savanna further offer different economic potentials, ranging from woodland for forestry to grassland for grazing. The formation of these various savanna patterns is known to be influenced by many variables, which include various physical attributes such as soil characteristics and topography, and physiological factors such as rooting depth. However, in the last ten years or so, five intimately related ecological factors have been recognized on a functional basis as the key determinants of savanna ecosystems, where each accounts for a range of physical and biological variables. These are: plant available moisture (PAM), plant available nutrients (PAN), fire, herbivory, and anthropogenic factors, such as various prehistoric and historic land uses (Scholes 1990). Rare catastrophic events, such as severe droughts, outbreaks of insects, and major human interventions, are also recognized, but they tend to be considered seperately as specialized conditions.

During the last decade, UNESCO has developed a programme known as 'Responses of Savannas to Stress and Disturbance' (RSSD, Frost *et al*



PAM = Plant Available Moisture
PAN = Plant Available Nutrients
H = Herbivory
F = Fire
A = Anthropogenic factors

R, L, C, P represent a range of scales at which each determinant has a significant control, where: R = region; L = landscape; C = catena; P = patch.

Figure 1.4. Two hierachy models of savanna key determinants (after Solbrig 1990: Fig.9:26, and additional text; Stott, pers.comm. 1992).

1986), the chief aim of which is to study savanna processes at a range of spatial and temporal scales, the understanding of which would help in decision making on the management of savanna resources. Most recently the programme has proposed a 'hierachy approach' (Solbrig 1990, see Fig.1.4)

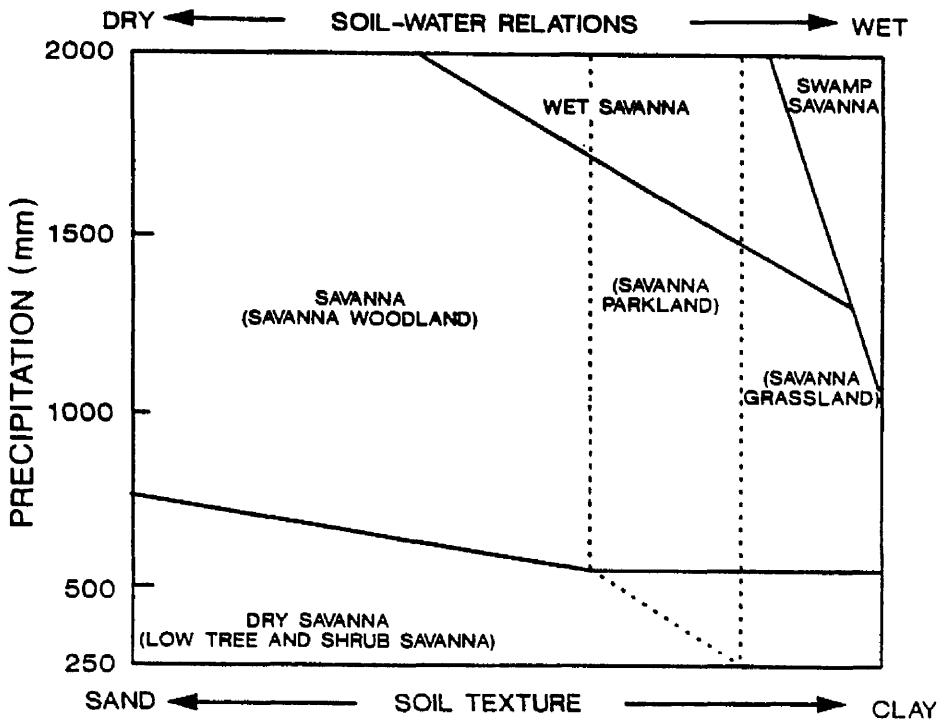


Figure 1.5. Johnson & Tothill's (1985) model of the distribution of savanna types, based on moisture availability.

based on the collective ecological expertise of researchers from savannas in different regions of the world. Due to the lack of extensive comparable quantitative data, this attempt to apply the tenets of hierachy theory mainly serves as an intellectual exercise to consider the relative importance of the main ecological determinants in this ecosystem.

As seen in Fig.1.4, the overriding importance of PAM is now generally accepted. Contradictory to some previous opinions (e.g.Cole 1986, Frost *et al* 1986), the influence of PAN is seen as secondary. It is not always of significance, and can be bypassed, linking PAM directly to the third level of the hierachy, namely fire, herbivory and anthropogenic factors. Accordingly, Belsky (1990), who reviewed various savanna models, found Johnson & Tothill's (1985) model based on two major variables of PAM, namely precipitation and soil texture, which relates to soil water-holding capacity, to be the most useful where detailed data is absent from the study area (see Fig.1.5). Thus savanna formations tend to range from moist woodland with high precipitation and free-draining sandy soils, to grassland with lower precipitation and clayey soils, to the most arid scrub savannas at the lowest precipitation on sandy soils. Fire

regimes and their significance vary greatly between these different savanna systems.

1.3.3.1 The fire regimes of savannas

With continuous fuel biomass distributed horizontally, surface fires are typical of savannas. Although individual tree-torching and crown fires do occur, they are generally rare, usually when conditions are very dry, hot and windy (Trollope 1984a), or on particular plant species such as the *Pandanus* palm in Northern Australia.

Fire regimes in savanna range quite widely in terms of their frequency, intensity, and extensiveness. Fundamentally, fire frequency depends on the rate of accumulation of flammable fuel biomass, which must be of a quantity and quality to sustain a burn, as well as the availability of sources of ignition. At a rough macro-scale, it has been found that fire is generally most frequent in moist savanna woodlands, where fire usually occurs annually or biennially, or up to a 5 years interval. Frequency then decreases towards the arid scrubland savannas, which occur at the semi-desert margin, and where fire may only occur every 5-50 years (Lacey *et al* 1982, Frost & Robertson 1987). It is also widely observed, however, that burns occur frequently, often every year, on derived grasslands where PAM is high enough to support good annual grass growth (e.g. Gillon 1983). Likewise, Haynes (1984) reports from Northern Australia that some floodplains are burned several times a year by the aborigines.

Frontal fireline intensity (I), on the other hand, depends largely on fuel biomass, the specific heat value of fuels, and the rate of fire spread, and it may be correlated with flame height (Byram 1959). Accordingly, in this respect, the important variables are fuel types, fuel species, and their relative quantities, climatic factors, and topography.

Fireline intensity in open grass savanna fires has been recorded to be higher than fires in tropical forests, with the former reaching up to 17,000 kW m^{-1} and the latter up to at least 7000 kW m^{-1} (Gill *et al* 1990). In Australian savannas, the grass fuel load varies from 50-300 g m^{-2} in inland dry savannas with short lived annuals, to 400-1200 g m^{-2} in moist savanna woodlands near to the coast (Lacey *et al* 1982). Thus, in all savanna formations, fireline intensity is likely to be highest on open, unbroken savanna grassland or woodland, where there is high moisture for good grass growth under open canopies that not only support grass, but allow for a hot micro-climate to aid ignition and the drying of fuel to give a greater heat yeild. This is particularly so

where fire is excluded for a number of successive years, so that grass species attain their maximum biomass production. It takes four years in the case of *Trachypogon* savanna in Venezuela and Colombia to achieve this (Medina 1982). Continuing absence of fire for >10-20 years, however, often leads to a reduction in grass productivity (Norman 1969, Medina & Silva 1990).

On a given fuel load, fireline intensity still varies markedly, both with climatic factors and topography. For example, an *Acacia* savanna in South Africa, yeilding an average fuel load of 380 g m^{-2}, burns with a fireline intensity ranging from 194-5993 kW m^{-1} (data from 10 experimental fires; see van Wilgen & Wills 1988). Higher fireline intensity is generally known to correlate with high air temperature, low relative humidity, and acute slope angles. Wind, and its direction, are also important, where **head fires**, which burn before the wind, generally give higher fire temperatures and a higher fireline intensity than do **back fires**, which burn behind the wind.

Calculated from flame heights recorded by Trollope (1978) in South African grassland, fireline intensities of head fires were found to be *c.*2437 kW m^{-1} while back fires were significantly lower at only *c.*160 kW m^{-1}. But, at ground-level, Trollope (1984a,b) considered back fires to be more 'intensive' than head fires, with a duration of temperature of around 95°C some 20 s longer in the former than in the latter. Average temperatures under back fires at this level are also more or less the same (around 330°C) as those under head fires, but sometimes higher, although the range of temperatures under head fires can be much greater (Potgieter 1974, after Trollope 1984b, Table 5 & 6: 211).

The extensiveness and patchiness of a burn depends on the general mosaic of flammable fuels and on favourable climatic factors, such as atmospheric temperature and wind. On the whole, savanna fires often burn in patches that are irregular in both space and time (Sukwong & Dhamanitayakul 1977, Frost & Robertson 1987). This allows for the common occurrence of less fire-tolerant species or those with a vulnerable seedling stage in frequently burned savannas, such as *Brachystegia* and *Julbernardia*. But within a given formation, the extent of fire spread and patchiness are much influenced by the seasonal and daily timing of the burn.

1.3.3.2 The ecological significance of fire and its seasonal timing in savanna

Most savannas are well adapted to fire physiognomically,

physiologically, and phenologically. Trees generally have thick bark, and many can produce sprouts from underground root buds. An extreme case is seen in subterranean trees, like *Anacardium humile* St.Hil. in South America (Coutinho 1982). Hemicryptophytes, chamaephytes, and geophytes are also common. Most ground cover species in Brazillian *cerrado* need fire to trigger off mass flowering, regardless of the time of the year (*ibid.*). Some *cerrado* species, like *Anemopaegma arvense* (Vell.) Stellfeld.ex de Souza. and *Nantonia nummularia* Decne., release seeds shortly after a burn, while a few species require fire for seed germination, as in some shrubby *Mimosa* spp. Heat from surface fires is also observed to stimulate greatly the germination of buried *Themeda triandra* Forsk. seeds in South Africa, although burnt seeds on the ground surface do not germinate (Trollope 1982). This grass is like many other savanna grass species. These fruit at the beginning of the dry season, and their seeds become buried in the soil with the aid of hygroscopic awns and seed-harvesting ants, thereby being protected from both bird predation and fire (Braithwaite 1990, Gill *et al* 1990, Yadava 1990).

Although adaptive traits to drought and fire are often shared, some traits are more characteristic of one of these constraints. On the whole, fire adapted mechanisms decrease along the dry axis (Huntley & Walker 1982: 657). Thus perennial grasses, being more effective in coping with fire than annuals, tend to be dominant in the most fire-prone formations. In the reverse situation, annuals are more adaptive to drought, and are dominant in arid savannas with infrequent fire. Likewise, frequently burned moist savannas tend to favour woody species with vegetative regeneration, while arid savanna species are more fire-tender and depend largely on seed reproduction and establishment during the long fire-free interval. A fine comparative example is seen in Australia in the difference between the dominance of *Eucalyptus* spp at the moist end of the scale and *Acacia* spp at the arid end. The more drought-tolerant *Acacia* is less fire-tolerant, having a thinner bark, and lacking the capacity to regenerate vegetatively underground (Walker & Gillison 1982).

Following a clearance, fire may induce savanna formations in the closed forest zone, where conditions are particularly favourable for woody plant growth, although there is some evidence that a low-to-medium fire intensity alone cannot always maintain such derived savannas (Trollope 1982). Otherwise, where there is enough moisture to support abundant grass fuel for frequent fires, fire usually helps to maintain formation structures by limiting the successes of woody plant establishment and maintaining poor soil status, unless savanna occurrence is

primarily edaphically determined by PAN, in which case the role of fire diminishes.

There are of course some exceptions. In Kruger National Park, South Africa, fire exclusion in some localities leads to the gradual disappearance of fire-dependent woody plants, such as *Dichrostachys cinerea* Wight & Arn. and *Acacia karroo* Hayne & Arzneigew, which give way to competitive grass domination (Trollope 1982). But overall, the impact of fire frequency on savanna structure depends on the degree and composition of plant recovery between fires. This in turn relates to a wide range of interacting variables, such as plant available moisture (PAM) and nutrient regimes (PAN), the extent of grazing and browsing, and the season of fire, and its intensity.

Variation in fire timing is governed by the initiation, length, and termination of the fire season, which are controlled above all by PAM, and by the temporal patterns of fuel characteristics and fire climate. In moist savannas, fires burn mostly during the dry season and early wet season, while arid savannas may burn at any time of the year, after one or more seasons of above average rainfall which produces enough grass fuel (Frost & Robertson 1987).

The effects of different fire times are two-fold: first, different times of burn yield different average fireline intensities and different extensiveness and patchiness in burns. Secondly, timing affects the responses of plants through their phenology, plant energy, and soil moisture reserves. Accordingly, fire timing affects both species composition and the productivity of the individual species, and thus the ratio of woody/grass components, fuel accummulation, patchiness of the burn, as well as the timing and availability of nutritious grazing.

On the whole, early season fires are known to be the least severe, burning in a small mosaic pattern, with low fireline intensity and low temperatures, in patches where the fuel is partially green, but just dry enough and of sufficient quantity to sustain fire (e.g. Hopkins 1965, Gillon 1983). The hours exhibiting favourable climatic conditions for a burn during the early season are also limited, and fires often expire at night. Burns occurring later in the season are generally more extensive and possess a higher fireline intensity, while Hopkins (1965) found that later fires consumed an average of 84% of the ground cover, compared to only 25% consumption in early burns.

In Northern Australian savannas, Gill *et al* (1990:164-5) observed that: "as the dry season progresses... the grasses desiccate further and semi-deciduous or deciduous shrubs and trees... shed leaves

which not only add to the litter fuel weight but also promote a continuous layer of fuel. Fires become more intense and more continuous and burn throughout the night at the height of the dry season. Towards the end of the dry season, a single fire may have burned hundreds of square kilometres." However, work done by Braithwaite and Estbergs (1985) has shown that, on average, late season fires are not, in fact, as intensive and extensive as mid-season burns, and indeed tend to have a lower scorch height. This is also the case in East Australian semi-arid woodlands, where climatic conditions are most favourable for burns during mid-summer (Hodgkinson 1991).

Few satisfactory temperature measurements for different burn times have been made. On Nigerian derived savanna, Hopkins (1965) found early season burns to attain temperatures of not more than 66°C, and the flames never rose above 3 m from the ground. Late season burns attained temperatures of >538°C up to 3 m, sometimes maintaining >100°C at 6 m above the ground, or more. On grass savanna in Senegal, late season burns reach 90-140° C at ground-level, 285-560°C at 0.5 m, and 140-375°C at 1.4 m, which is considerably less than recorded for Nigerian savannas (Pitot & Masson 1951, after Hopkins 1965). In Senegal, no temperatures above 200°C have a duration of longer than 30 s, whereas temperatures above 50°C at ground-level are maintained for 1-3 min.

The characteristics of different fire timings naturally have varying effects on the plant community. Any evaluation of these differences requires quantitative data from long-term experiments, most of which have been carried out on African humid savannas or relatively moist formations, usually on plots subjected to at least three different treatments, namely complete fire protection, annual early burns and late season burns (e.g. Trapnell 1959, Ramsey & Rose-Innes 1963, Rose-Innes 1972, Scott 1972, van Rensburg 1972, Brookman-Amissah *et al* 1980). It has been commonly found in Africa that early burning, with its low fireline intensity, does little harm to the woody component, where regeneration of canopy species is generally maintained or increases slowly. Often, the mosaic nature of early burns leaves a patchy cover of tree and shrub seedling clumps. Conversely, late burns, with high fireline intensity, appear to be destructive to woody species, except to the most fire-tolerant. At the other extreme, the protected areas are usually invaded by many closed-forest species.

The extent of the impact of fire timing on savanna structure varies between sites and within vegetation communities. Where the climate is relatively wet, and the observed savanna is within the proximity of

moist forest, as seen in the derived savannas of Kokondekro in Ivory Coast and Olokomeji in Nigeria, tree density has become high after 30 years of experiment, with values in the early burned plots being almost as great as in the protected areas (Ramsey & Rose-Innes 1963). By contrast, but for a similar time span, studies in the drier Red Volta Forest Reserve in northeastern Ghana, which is far from any closed forest, showed tree recruitment to be much lower comparatively, with large differences in tree density between protected and early burned plots (Brookman-Amissah *et al* 1980).

More recently, a 12-13 year-experiment in *Eucalyptus* forest and woodland at Munmarlary, Northern Australia, appears to challenge the African experience. Although there were developments of dense understorey, no change of structure has taken place in the protected areas (Bowman *et al* 1988), and tree seedlings remain as ground cover, despite having once grown up to mid-canopy height in the middle of the observation period (Briathwaite, pers.comm.). While a similar pattern also occurred in Katherine, Northern Territory, where no apparent bush encroachment took place after 5-10 years absence of fire (Norman 1963, 1969), the low open savanna forest grows on clay loam which could impede drainage (Fig.1.5). Fensham (1990) argues that the Munmarlary savanna forest is not a clear case of an edaphic formation, as he compares the deep red earth of this site to the rocky shallow soil of Solar village, where a denser structure characterizes the protected area.

However, Lonsdale and Braithwaite (1991) have pointed out a few problems in regard to the interpretation of the Munmarlary experiment. These include the small size and few replicates of the experimental plots, the artificial practice of re-burning the unburned patches left after early burn sites, which minimizes the characteristic difference between fire treatments, and the insensitivity of the methods used in both the sampling and the analysis of the data.

All the work described above has been carried out in rather moist savannas with frequent fires, and differnt patterns may well be seen in the drier savannas. In East Australian semi-arid savanna woodland, where fire is a relatively rare event, Hodgkinson (1991) found all levels of fireline intensity to kill an equal proportion of around 50% of shrub seedlings, but seed germination of some species increased with the fireline intensity. Consequently, the hottest mid-season burn should recruit the highest number of shrub seedlings.

Another picture is also seen in South America where most woody species are evergreen. These grow and change leaves during the dry season

(Medina 1982). Dry season fires often stimulate new buds, and are less damaging to plant energy reserves than wet season fires, which occur when no new leaves are being produced (Sarmiento & Monasterio 1983).

In contrast to the woody component, the grass cover in Africa tends to be favoured by late season burns. In Natal, South Africa, for instance, Scott (1972) found the basal area of grasses to be 505 m^2 ha^{-1} in protected areas, 1255 m^2 ha^{-1} in early burn plots, and 1490 m^2 ha^{-1} in late burn plots, after 32 years of experiment. The reasons given by scientists are two-fold (Rose-Innes 1972, van Rensburg 1972, Philips 1974, Brookman-Amissah *et al* 1980, Medina 1982, Mott & Andrew 1985, Gill *et al* 1990, Medina & Silva 1990). Firstly, the reduction of grass cover can often be correlated to the shading and competition from the increasing woody component, particularly at wetter sites, where there is enough moisture to support abundant tree growth, as in Kokondekro and Olokomeji, where grass disappeared, respectively, within 24 and 27 years of fire exclusion.

Secondly, there is a relationship with the temporal pattern of energy reserves in the perennial grasses. Unlike the annuals, which depend entirely on seeds for their reproduction, perennial grasses also reproduce vegetatively from energy reserves which they store underground during dormancy in the dry season. It is therefore common to find that very early burns, right at the end of the growing season when the grass is partially green, are detrimental to the plant, which has not yet stored away all its energy reserves. Furthermore, regrowth from too early a burn, even on dormant grass, can become dessicated *before* the next rains, and this leads to poor biomass production from replenished reserves in the following season, as is the case in *Trachypogon* savanna in South America (Medina 1982, Medina & Silva 1990). Growth from too late a burn, on the other hand, can be severely impaired, since soil water reserves are used up at the end of the dry season, before the first rains. Otherwise, mid-season and rather late-burns tend to produce good vigorous growth, as green production after fire is sustained until the first rains. There are, of course, some exceptions to all this. The long experiment at Red River Forest Reserve in Ghana showed that there was little difference in the basal area of grasses burned either early or late in the season (Ramsey & Rose-Innes 1963, Brookman-Amissah *et al* 1980).

The different timing of fire further selects different floristic communities, chiefly through variations in fireline intensity. In West Africa, as with the Red Volta Forest Reserve experiment, tall grasses, which are believed to compete better with the woody component,

are dominant in protected and burned plots with a moderate fireline intensity, while high fireline intensity, late burns tend to favour shorter grass species (Ramsay & Rose-Innes 1963). This is important for grazing, since the much favoured tall grass, *Andropogon gayanus* Kunth., is encouraged by early burns, whereas shorter grasses in late burned sites are dominated by the coarse, unpalatable *Loudetia acuminata* (Staphf.) C.E.Hubbard.

Likewise, *Brachystegia-Julbernadia-Isoberlinia* woodland in Zambia is well-maintained by an early burning regime, whereas 11 years of annual late burns showed a strong tendency to transform the woodlands into a more fire-tolerant community (Trapnell 1959). It is therefore common to find that species diversity is often greatest under moderate fire regimes, although high fireline intensity can select for specialized species that would otherwise be absent.

Finally, the season of fire timing can sometimes be crucial for plant sexual reproduction. Trollope (1982) found that mid-dry season burns in South Africa resulted in large seed production of the grass *Themeda triandra*, while burning after the early rains prevented seed production. However, similar examples elsewhere have been rarely reported.

The complete picture of fire effects on nutrient cycling and soil in savanna is not yet available (Huntley & Walker 1982, Proctor 1990), but there is a tendency to show that, in the long term, fire maintains the soil status, at least in many savanna systems. In Brazillian *cerrado*, Coutinho (1982) found that the herbaceous plants and other ground cover are very efficient in their uptake of most of the available nutrients that are temporarily concentrated on the upper soil layer after a burn. Likewise, Kellman and Saumugadas (1985) and Kellman *et al* (1985) record Neotropical savanna soil-vegetation systems to be highly retentive of nutrients and well resistent to short-term nutrient losses caused through leaching, with or without fire. There is further evidence to suggest that local nutrient losses to the atmosphere by burns in some Australian savannas may be closely correlated to subsequent nutrient gain *via* rainfall (Holt & Coventry 1990). On the other hand, reduction of soil moisture content caused by burning is reported to be significant, and particularly detrimental to arid African savannas (West 1965, cited after Trollope 1982). And like grazing, burning exposes the soil surface by removing ground vegetation cover, making it susceptible to erosion and to the loss of nutrients through run off, especially on steep slopes at >7° (Komkris *et al* 1969) in the areas with heavy downpours. However, fire effects on soil erosion are likely to vary with the seasonal timing of the

burn and with the rate and nature of the vegetation recovery, although experimental work is needed to test this.

With regard to soil nutrients and fire timing, long-term projects in Zambian *miombo* woodland (Trapnell *et al* 1976) and north-eastern Ghana savanna (Brookman-Amissah & Hall 1980) have shown that there is little overall difference either between plots burned at different times or between burned and unburned plots, except the protected plot in Ghana experiment, which carried more organic matter and total nitrogen than the burned areas. On the other hand, 30 years of experiment in Olokomeji, Nigeria, demonstrated that, not only are the levels of organic matter and most elements greater in the topsoil of the plots burned early in the season than in late-burned sites, but also that the levels of organic matter, nitrates and available phosphorus in the early-burned plots are higher than in the protected areas (Moore 1960).

However, while late burns appeared to maintain the soil status in this study and early burns increased fertility, Moore (1960) sees the difference between early-burned and protected topsoil to be related more to the vegetation community, where the latter reflects a closed forest ecosystem rather than a savanna, with its significant grass root system.

A knowledge of fire timing is therefore most important for any local fire management programme where the objectives are clear. It is not simply a choice between promoting grass for pastoralism or conserving woody species for forestry. A local understanding of fire timing and its characteristics, in relation to plant phenology, animal behaviour and the general level of adaptation to fireline intensity and fire extent in a given terrain, is crucial in all savanna resource management. Northern Australian Aborigines, for instance, are known to use fire timing and placement as a major tool in their own traditional regimes (Haynes 1984), and these can be the most effective and economical means of fire control. Unfortunately, long term quantitative data which incorporates a full set of important ecological questions is still lacking for most savanna areas. And anyway, traditional fire management systems, if they survive at all, cannot be wholly extrapolated to handle the present situations, which are now so often totally different from those in the past.

1.4 The recent past and current trends in fire management in savannas

The arrival of European settlers in the tropics brought about some fundamental changes in fire management. During the earlier period of colonization, European perceptions towards fire and traditional practices

varied greatly from indiscriminate 'burning off' by pastoralists in Australia to unsuccessful attempts at complete fire protection by British foresters in India and Burma (for details, see Pyne 1990). In the latter case, fuel build-up inevitably led to large, intensive, accidental fires during drought years, and the regeneration of fire-dependent *sal* (*Shorea robusta* Gaertn.f.) forests ceased throughout fire-protected areas.

Yet, despite the experience of British India, which, by the beginning of this century, had led many workers to accept that fire is an indigeneous ecological factor in the tropics, the 1930s saw a reversal in this general perception, with wildfire increasingly regarded as an alien destructive force, rather than a useful tool (Kozlowski & Ahlgren 1974). This was perhaps catalysed by the reckless 'burning off', which was followed by an extensive campaign stressing only the harmful effects of fire. Nevertheless, in spite of all this negative publicity, there has been a significant increase in fire occurrence throughout large parts of the tropics, within at least the past 50 years (e.g. Gill 1981, Lacey *et al* 1982), with some possible exceptions, as in certain areas of South Africa, where fewer fires are now used since the introduction of the Soil Conservation Act in 1946 (Trollope 1984a). Unfortunately, actual quantitative records of past fire events in the tropics are not readily available, with the monitoring of fires by satellite remote sensing still in its infancy (Malingreau 1990). Much of the presumed increase is due to the recent extensification of rural land use and increasing encroachment into wildland. Easy accessibility to remote areas, with logging and other forms of exploitation of wildland, has brought about widespread and frequent fires.

The causes of fire range widely, but many authors agree that in Australia, South America and South Africa, the most common causes are related to agriculture, particularly for improving pastoralism (e.g. Luke 1962, Budowski 1967, Batchelder 1968, Coutinho 1990). Other causes range from accidental fires, such as sparks from railways, dropped matches, or even from releasing festive balloons in Brazil, to accidental fire-spread derived from intentional fires, such as camp fires, rubbish burning and roadside burning, or even from ground preparation to collect *mahna* flower (*Madhuca indica* J.F.Gmel.) in North Central India (Saigal 1990). Lastly, there are deliberate fires, such as those used in hunting and path clearance, to induce new growth, or fires set simply for fun.

Encroachment into forests has led to the spread of derived savanna formations, such as the extensive colonization by *Imperata cylindrica* (L.) Beauv. grassland in tropical Asia and *I.brasiliensis* Trin.

in tropical America (Mueller-Dombois & Goldammer 1990), which alter the local fire regimes, leading to a sweeping uncontrollable wild fire with a very high fireline intensity, and with flame heights of up to 20 m, like those occurring in North Thailand (Boonplian 1985). Because of such events, much of the existing savanna formations have become severely degraded with repeated burning and grazing, and they are now often reduced to semi-desert scrub lands, exhibiting severe sheet and gully erosion (For detail of processes, see e.g. Hirsch 1987, Goldammer 1990, Hafner 1990, Werner 1991).

Increasingly, land managers and scientists today have come to acknowledge the urgency for research into sustainable fire management schemes related to the current stresses in the savanna areas, which comprise about 40% of the tropical land surface (Solbrig 1990) or nearly a third of the world's land surface (Werner *et al* 1990) and which support nearly one fifth of the world's population (Frost *et al* 1986). The real figures are probably much higher as these actually relate only to those areas commonly classified as savanna lands (Fig.1.2).

The most technologically advanced forms of savanna management are practised in Australia and in Texas, where computer-based DSS (Decision Support Systems), with a range of user-friendly software designed for specific problems, such as SHRUBKILL for choosing an appropriate fire prescription to control shrubs in East Australian savannas, are generally employed (Ludwig 1990). The most successful packages incorporate problems users actually face in the field, and take into account their economic interests and existing forms of management (Stuth *et al* 1990, Winter 1990).

However, such methods are only viable in cultures where information systems and computer technology are well developed and integrated into everyday life, and where there is enough relevent data for the system inputs. In some cases, where the use of computers is inappropriate, or computers are not available, simple wall-charts and well-designed manuals should be the preferred alternatives. But for most parts of the developing tropics, little ecological data and information on local management systems are available.

As van Wilgen *et al* (1990) have pointed out, the objectives for fire management in national parks and other conservation areas tend to be less specific than in agricultural areas, where management prescriptions are based on the local biology of particular plant species, or in wood plantations where the main objective is usually to reduce fuel load. In conservation areas, the general aim is mostly to maintain the

Table 1.3. Causes of fire in North and West Thailand.

CHIANG MAI PROVINCE (N.Thailand)		HUAI KHA KHAENG W.S. (W.Thailand)	
Unknown	44%	Path clearing	more frequent
Path clearing	?	Unknown	
Swidden fire	26%	Swidden/field burning	
Minor forest product collection	9%	Forestry officials	
Fire-break burning	6%	Road-side fire	
Arson in plantations	5%	Hunting	
Hunting	1%	Camping fire	less frequent
Tourist development (Elephant camp)	1%	Arson (e.g.land use conflicts)	
By illegal timber cutters	1%	For fun	
To induce grazing	0.3%	Military purposes	
		Induce young growth (other than for grazing)	
		Nutrient wash from hill ridges to fertilize fields	
		Cigarette ends	
Mather & Maneeratana (1978)		Social survey, 1988*	

* based on rating given by 19 respondents from 17 villages along the boundary of Huai Kha Khaeng Wildlife Sanctuary (see Section 4.6)

biodiversity of the ecosystems, and for maintaining scientific and scenic resources for tourism. In the parks where the important role of fire is recognized, attempts are usually made to recreate 'traditional' or 'natural' fire regimes under which the life forms are believed to have evolved. However, more often than not, information on the area's fire history is not available, and consequently fire prescriptions are based on research done elsewhere, as in many South African national parks (van Wilgen *et al* 1990).

Furthermore, even where some traditional knowledge and practices are preserved, their duplication, if still feasible at all, may

not neccessarily be wholly appropriate to the present-day situation, and some modifications based on multi-disciplinary research will usually be needed. Such a challenge is now facing the managers of Kakadu National Park, Northern Territory, Australia (a World Heritage site), where traditional Aboriginal fire regimes, although still in existence, have probably been altered or largely lost in many respects, and the new ecological situation, with a significant introduced fauna, poses new problems (Gill *et al* 1990; Braithwaite, pers.comm.). A form of computerized DSS programme, which Gill *et al* (1990) refer to as a rule-based 'Expert system', is currently being explored for fire management in the Park.

1.5 Forest fire policy in Thailand and Thai savannas

1.5.1 Causes of forest fires in Thailand

Forest fires in Thailand are largely human-induced. In 1976, Mather and Maneeratana (1978) made a preliminary survey of the causes of fire in Chiangmai province, North Thailand, and found that 47% are from unknown causes, while the rest range from intentional to accidental burns and accidents from intentional burns (see Table 1.3). Path clearing[6], in particular, was believed to be a major cause, although this is difficult to prove. The same is also true of Uthai-thani province in West Thailand, where I carried out interviews and a questionnaire survey in 1988[7]. Natural fire is believed to be rare in Thailand, although there has been a report of an annual fire occurrence in West Thailand caused by the sun's rays being reflected from crystallized rock surfaces (Vayanonda, pers.comm.). Many workers (e.g. members of the Forest Fire Control Unit) reject entirely the possibility of fires caused by lightning strikes in Thailand, on the assumption that there are no dry thunderstorms. Fire caused by bamboo-rubbing is also often considered an old wives' tale.

In contrast to these wide-spread beliefs, the above mentioned interview-questionnaire survey found that 5 out of 19 respondants from 17 villages situated within or along the forest edge of Huai Kha Khaeng Wildlife Sanctuary (see Section 3.8), each claimed to have witnessed at

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[6] This is not a clearing process restricted to a narrow pathway as is often misunderstood. In this context, 'path clearing' by burning is simply to burn away litter and ground cover to ease movement, or to reduce noise from treading. Too much sound would be a disadvantage in hunting.

[7] This social survey was originally intended to form part of this thesis, but it was later dropped in order to limit the research focus of my work.

PROVINCE	MONTH												
	J	F	M	A	M	J	J	A	S	O	N	D	
Chiangmai	0	0	1	2	1	0	0	0	0	0	0	0	mean
	0	1	4	12	6	0	0	0	3	3	0	0	maximum
Nakorn-sawan	0	0	1	4	3	1	0	0	1	1	0	0	mean
	0	1	5	8	8	5	2	4	4	6	1	0	maximum
Korat	0	1	2	7	3	1	0	0	0	1	0	0	mean
	0	3	8	14	10	7	4	2	4	5	2	0	maximum

Table 1.4. Mean and maximum number of detectable dry thunder days, 1971-1990.

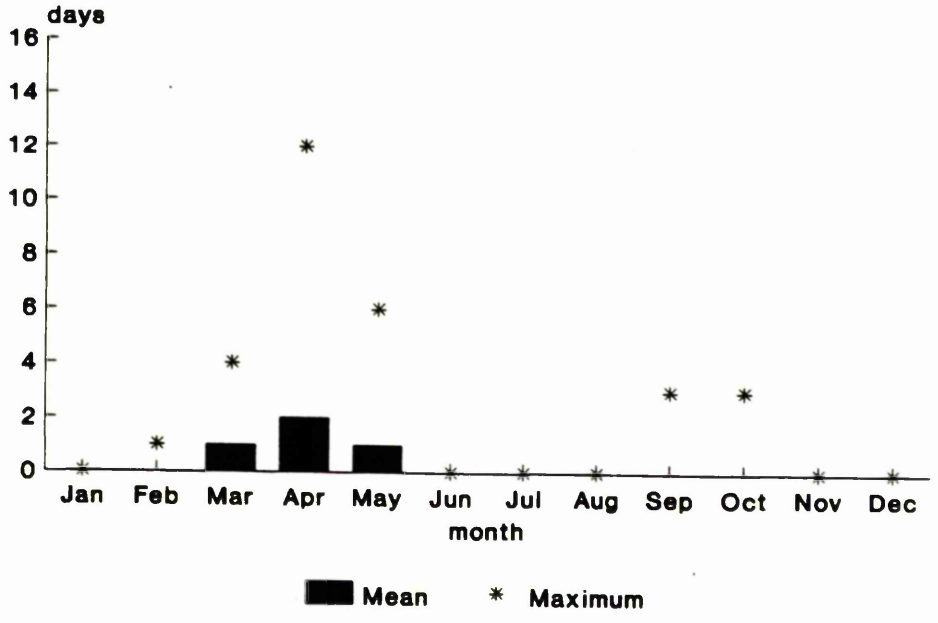


Figure 1.6a. The mean and maximum number of detectable dry thunder days, Chiangmai province, North Thailand, 1971-1990.

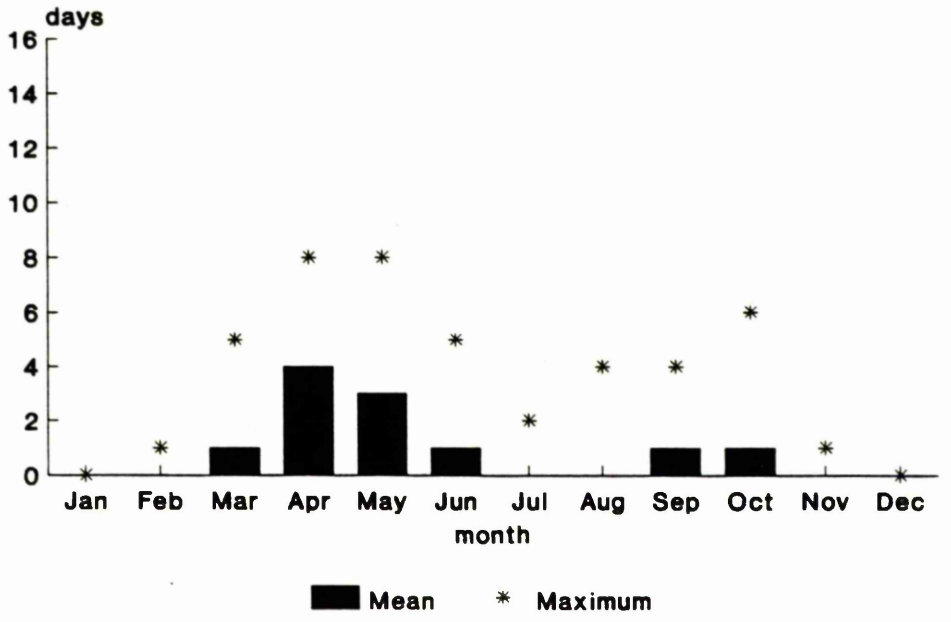


Figure 1.6b. The mean and maximum number of detectable dry thunder days, Nakorn-sawan province, Central Thailand, 1971-1990.

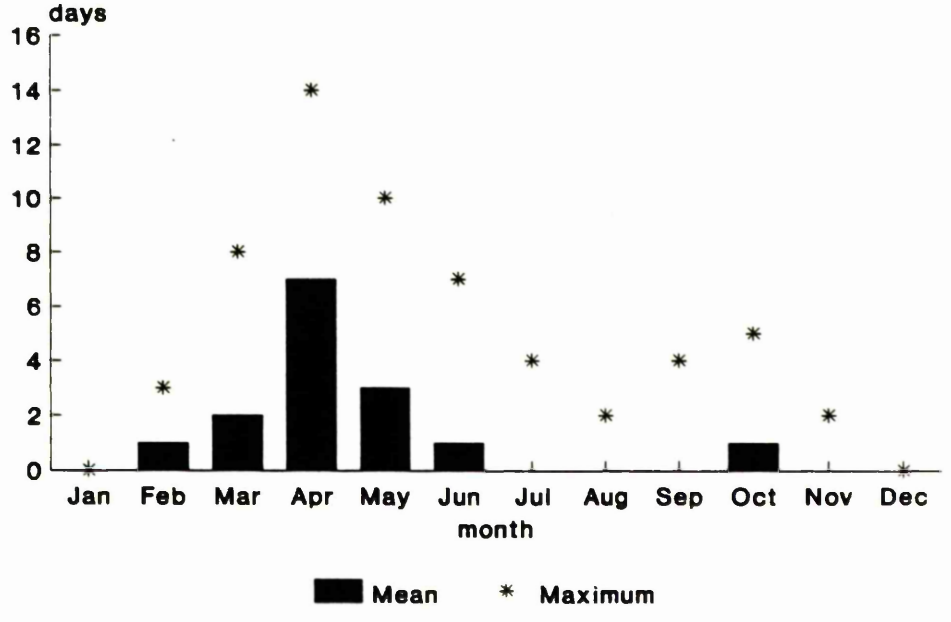


Figure 1.6c. The mean and maximum number of detectable dry thunder days, Korat province, Northeast Thailand, 1971-1990.

least one fire caused by lightning. This is said to happen usually with the onset of the early Southwest monsoon when thunder is accompanied by a small amount of rainfall, normally in April or May, and occasionally June, igniting dry fuel accumulated over the dry season. Stott *et al* (1990) also found that a smouldering tree, torched by lightning strike, can sometimes lead to fire after the storm has passed. In addition, one respondant from the social survey has witnessed a fire caused by two bamboo culms rubbing together while he was camping near a bamboo area on a hot and windy evening in late March at the end of the dry season.

Table 1.4 and Figs 1.6a-c show the mean and maximum number of detectable dry thunder days occurring in each month from 1971-1990 (20 years) in three localities. Since the meteorological data does not show the exact dates of rainy and thunder days, it is not possible to know precisely how many days rain and thunder may occur simultaneously. The only known number of dry thunder days (i.e. when rain does not occur with thunder) are those which are derived by subtracting the number of rainy days from the number of thunder days recorded each month. The localities are Korat (Nakorn Ratchasrima) province in Northeast Thailand, Chiangmai province in the North, and Nakorn-sawan province in Central-West Thailand, which is the nearest large meteorological station to the study site of this thesis (Uthai-thani province, West Thailand). At all sites, April is the month with the highest number of dry thunder days, particularly in Korat, where, in 1971 and 1986, nearly half the month experienced dry thunder (mean = 7 days). The number can also be high in March, and especially in May. These months fall within the range of possible late dry season or early rainy season burns, when fuel can still be dry, depending on the amount of moisture it receives prior to the event of dry thunder.

The number of dry thunder days can, of course, vary quite a lot from year to year. Nevertheless, this shows that wild fire caused by lightning strike is very probable in Thailand, albeit uncommon. But in some localities, it is likely to have been less rare than is generally thought.

1.5.2 Forest fire policy

Most fires, however, remain human-induced, so much so that when J.C.Macleod was sent over to the Thai government from the Canadian International Development Agency (CIDA) in 1971 as an expert in forest fire control, he was aghast to find that "the attitude of the public in Thailand towards fire in the forests is such that almost anyone entering or working therein during the fire season is a very serious threat of

forest fire" (Macleod 1971:10). Yet, whether Macleod was right or not in his assumptions with regard to the 1971 Thai perception of forest fires, the media, popular journals, as well as most official and many academic papers since the 1980s, have mostly taken a strong stance against forest fires (e.g. Akkasiri 1984; Boonplian 1985; Settarak et al 1986, 1987; Duangkhae 1987; Pancharoen, *The Nation*, 20/4/1988; Nakhasathien & Stewart-Cox 1990; Sangprateep, *Thai Rath*, 26/8/1991; 'Khon Pa' 1992; and to a lesser degree, Ketupraneet *et al* 1991). Akkasiri (1984:1) went as far as saying that the 'silent force' of forest fire is far more destructive than capitalists' mechanical logging.

Such an attitude is partly due to the dominance of human-induced fires as opposed to natural fires, but also partly reflects the alienation of modern-day society from nature and its elements (Stott 1988b). Above all, it is the product of an orthodox forestry training and the publicity campaign emanating from the Thai Royal Forest Department (RFD), which was formed in 1896 chiefly to control logging at the national level, when there was fierce competition among western companies for timber concessions in teak (*Tectona grandis* L.f.) forest (Chaipet 1980). Consequently, preservation of timber supplies became the major goal of forest legislation until 1961, when the Wild Animal Reservation and Protection Act was passed. But even then, conservation was geared towards species preservation rather than ecosystem maintainance (Hurst 1990), while timber still remained very much at the heart of the Royal Forest Department's concern.

It was against this background that Macleod was sent over to assess the forest fire situation, and to make recommendations "relating to the protection against fire for the forest of Thailand" (Macleod 1971:1). With such preconceptions, and after spending eight months in Thailand, he outlined the basis from which forest fire policy has subsequently been formed. In this report, the need to study forest fire ecology was *never* once raised, since fire was clearly detrimental to the timber yeild, as "..even when trees in a burned-over area bore no visible evidence of harmful effects, the fire would often result in a serious loss of increment" (*ibid.*:5). Legislation was then renewed to control lighting wild fires. The Forest Fire Control Unit (FFCU) was set up, and trainees were sent abroad. Although Macleod (1971) did give some attention to prescribed burning, the general policy now is to protect completely all forests from fire, using fire fighting agencies and anti-fire propaganda.

Like Macleod, the western-trained officers who have now become Thai 'experts', have totally neglected the need to learn from local

residents. The Forest Fire Control Unit (Settarak *et al* 1986) conducted a questionnaire survey in Chiangmai, North Thailand, on 244 villagers to test their 'understanding' of forest fire damage, measured against 'official' knowledge; not surprisingly, they concluded that there is a serious need for an educational programme for the 28% who see fire as a neutral or a non-destructive force. The situation echoes what Curtis (1959:344) once said of Wisconsin 'savannas' (grasslands), which "have become victims of the bureaucratic dictum, that since most forest fires are the source of economic loss, therefore all fires are bad and must be prevented at any cost. This dogma has been supported by such an intensive propaganda campaign that there is danger of it being accepted as truth."

But the truth is that our knowledge of forest fire in Thailand is still rather superficial. As it will be demonstrated later in this thesis, there is very little real data available, although many assumptions have been made about forest fires. In effect, the Royal Forest Department's policy does not recognize the need for different fire management schemes for different vegetation types and localities.

Currently, the most extensive vegetation formation in Thailand is the fire-prone dry dipterocarp or dry deciduous dipterocarp forest. As it will be demonstrated shortly, this is essentially a savanna forest, which, more often than not, is not recognized even as a savanna formation (Stott 1984). Yet, it clearly represents a fine example of the moister end of the savannas, its characteristics being comparable with the African *miombo* and the dry *Eucalyptus* forests of northern Australia.

CHAPTER 2.

FIRE ECOLOGY OF THE SAVANNA FORESTS OF MAINLAND SOUTHEAST ASIA

2.1 Savanna forest: definition, nature, and origin of the term

True lowland open savannas exist in mainland Southeast Asia, but they are only of limited occurrence (Blasco 1983, Stott 1984), as, for example, at Ban Me Thuot in Vietnam, Mondolkiri in Cambodia, Kanjanaburi and Sakon Nakhon in Thailand, although much of the last site is now destroyed. In Burma, Kurz (1875, 1877) has also described such savanna grasslands along regularly inundated river banks, while Richards (1952) mentions the occurrence of 'savanna-like communities', which are locally known as '*kaing* grasslands' or 'elephant-grass jungles'. In addition, there are small, scattered areas, such as the grassy enclaves found in Khao Yai National Park and a proposed site for a nature reserve near Phu Khiew Wildlife Sanctuary, which provide important grazing lands for large herbivores, as well as some montane areas, known in Thai as 'bald hills', like those in the mountains of Petchaburi province (Fig.2.1a). Other open grasslands with or without scattered trees found in higher altitudes are, for example, the famous 'Great Field' in Thung Yai Wildlife Sanctuary (870 m.a.s.l., Fig.2.1b) and the open pine-savanna woodland of Thung Salaeng Luang National Park (800 m.a.s.l.).

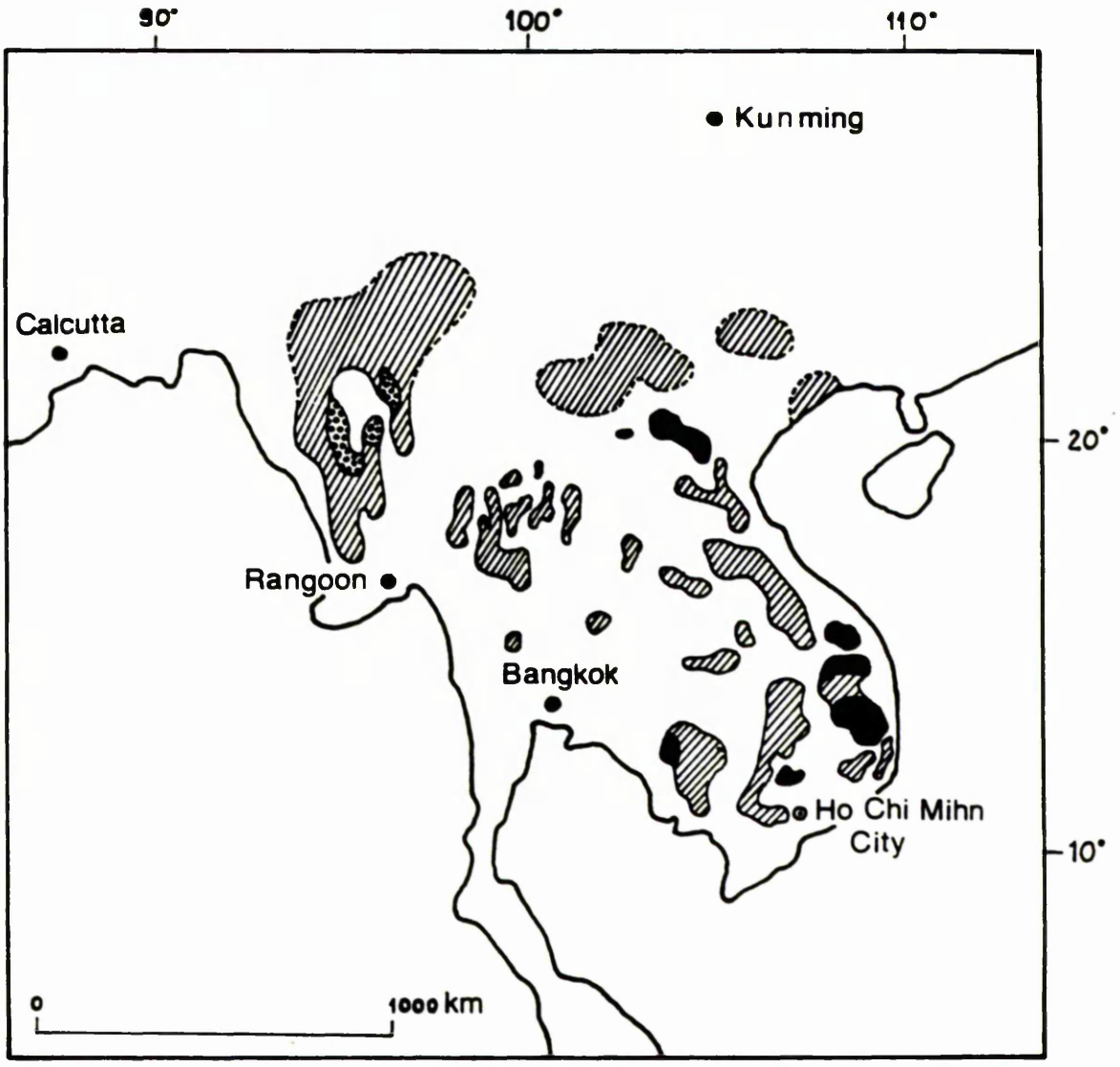
Outside savanna grasslands in the strict sense, Stamp (1925) recognises several types of the more closed 'savanna forests' in Burma, including *Diospyros* or *Te* forest, *Than-Dahat* forest, and the *Sha-Dahat* thorn forest, the latter falling on the border line of thorn and savanna forest. However, the most significant savanna formation in mainland Southeast Asia is undoubtedly the dry dipterocarp forest. In fact, this is also the most extensive 'natural' land vegetation cover in the region (Fig.2.2, Blasco 1983), although it has been largely neglected in most English texts on world savannas and in most general books on tropical vegetation (Stott 1984). Indeed, it is rarely considered as a 'savanna forest formation', despite its obvious structural and functional similarities with other widely recognized savanna forests in the Old World.

For example, in Huntley and Walker (1982) *Ecology of tropical savannas*, the Southeast Asian formations were not considered. Whitmore (1984) and Condominas [1980, in Harris (ed) *Human ecology in savanna environment*] subsumed it in a big bag of 'monsoon forest', by which is

Figure 2.1. Some true savannas of Thailand.

Fig.2.1a. One of the 'bald hills' of the Petchaburi mountains. (Photo by P.A.Stott).

Fig.2.1b. A part of the 'Great Field' of Thung Yai Wildlife Sanctuary. (Photo by N.Bhumpakkapun).



LEGEND

open savanna grassland

dry *Diospyros* forest / *Than-Dahat* forest (savanna forest)

dry dipterocarp forest (savanna forest)

Sources

1. Blasco (1983)
2. Lekagul & Round (1991:31)
3. Hall (1964:47,55)
4. Hundley (1961)

Figure 2.2. Map of savanna forests and open savannas in Southeast Asia.

meant tropical seasonal forests. Likewise, Walter (1973) passed over it simply as 'deciduous tropical forest'. Although Cole (1986) provides a small section on the Southeast Asian formations, where she uses the more precise term 'dry or deciduous dipterocarp forest', or at times 'deciduous open dipterocarp forest' after Blasco (1983), she never quite treats it as a savanna formation. In fact, among the major texts on world savannas, only Bourlière's (ed) *Tropical savannas* (Ecosystems of the World, 13), 1983, gives Southeast Asian formations any coverage worthy of note. Here, Blasco opts for 'open forest' after the '*forêt claire*' of the French-speaking botanists as a convenient general term for dry dipterocarp forests. Finally, and more recently, Werner (1991) has edited the *Journal of Biogeography*, 17 (1990), into a book form which covers both Asian and Australian savannas.

There are basically three reasons for this widespread ignorance of the Southeast Asian formations. First, it is because their status and origin are felt to be controversial (Cole 1984), a point which will be discussed later on in this chapter, and secondly there is a general lack of data. But the main reason is probably due to their essentially forested appearance (Stott 1984). Harris (1980), who refers to the Southeast Asian formations as 'drier types of monsoon forest', feels that what he classes as savanna woodland differs from "deciduous forest and woodland only in its more open structure and its better developed herbaceous layer" (Harris 1980:16-17). Likewise, Cole (1986:16), who, although she defines savanna woodland as "deciduous and semi-deciduous woodland of tall trees and tall mesophytic grasses", also specifies the spacing of trees to be "more than the diameter of canopy". Some workers in Southeast Asia themselves (e.g. Kutintara & Bhumpakkapun 1989, Nakhasathien & Stewart-Cox 1990) do not regard dry dipterocarp forest as a savanna formation chiefly on the ground of canopy formation. It is argued that a 'savanna forest' should not form a continuous canopy at all, and it is further implied that the rather different floristic composition between the true savanna formations in Thung Yai Wildlife Sanctuary and the dry dipterocarp forest should also differentiate the latter from the classification of 'savanna forest'.

But despite the frequent formation of a continuous canopy, the dry dipterocarp forests actually bear a strong resemblance to the *miombo* woodland of Africa (e.g. Menaut 1983), the dry *Eucalyptus* woodlands of northern Australia (Gillison 1983), and the *sal* (*Shorea robusta* Roxb.) forests of the Indian subcontinent (e.g. Sen Gupta 1938). Although these are certainly different floristically, their physiognomy and structure are

remarkably similar, with the characteristic species of each community occupying the same functional niches.

In contrast with the Neotropical savannas, where structures are markedly varied while the floristic components are retained throughout their biogeographical range (Sarmiento 1983), the structure of these old world savanna forests is more or less consistent, and they are relatively homogeneous in character. The dry dipterocarp forests, the *sal* forests, the dry *Eucalyptus* woodland, and the *miombo* woodlands all have a relatively closed top canopy formed of tall thick-barked trees, generally between 10-25 m high, and a ground cover of grasses and herbs. Fire resistant cycads are also present in most associations.

These formations present a fine example of convergent evolution where the different communities have developed a similar structure and physiognomy under parallel ecological stresses. All are associated with areas of relatively high rainfall, usually between 1000-1500 mm a year, but with 3-7 months with less than 25 mm of rain (Nix 1983). The soils are generally acidic, highly leached, infertile, sandy to sandy loam or rocky soils, often with a laterite layer. Temperature is warm throughout the year (mean values for the coldest months are usually over 20° C), and fire is a common ecological stress.

Some of the workers who regard some or all of these formations as 'savanna forest' do recognize the problem of the distinction between savanna forest and true open savanna (e.g. Walter 1973, Blasco 1983, Stott 1984). Stott (1984:317) comments that it is "arbitrary in character and above all depends on the degree of closure of the canopy in the upper stratum of trees". He supports his own differentiation with Schimper's (1903) classification of tropical climatic woodlands and grasslands, where tropical savanna forest is "more or less leafless during the dry season, rarely evergreen, is xerophilous in character, usually, often much, less than twenty meters high, park-like, very poor in underwood, lianes, and epiphytes, rich in terrestial herbs, especially in grasses" (Schimper 1903:260).

This formation, Schimper (*ibid.*) recognized to relate well to the 'open forests' of Burma described by Kurz (1875, 1877), who was one of the first to acknowledge the extensiveness of seasonal forests in the tropics, and the first to describe dry dipterocarp forests systematically in English, and at least once he actually called it 'savanna forest'. To Schimper (1903), these savanna forests are quite different from true monsoon forests which he distinguishes as taller and "tropophilous in character...rich in woody lianes, rich in herbaceous but poor in woody

epiphytes" while still "more or less leafless during the dry season". On the other hand, savanna forests differ from true tropical grasslands or savannas in that trees are "at greater or less distances apart" (*ibid.*:364), and of different species and characteristics from the forest, but "when the trees become closer, the savanna(h) passes over into savannah-forest" (*ibid.*).

Stamp (1925), Richards (1952), Sewandono (1956) Ogawa *et al* (1961) and later Stott (1984), have all followed Schimper in regarding the dry dipterocarp forest as a savanna forest. And if we accept the general definition of savanna vegetation given in Chapter 1, then any tropical seasonal formations bearing the essential character of Schimper's 'savanna forest' must also be included in all general discussions on savanna ecosystems, for they share *similar ecological processes*. It is 'savanna' because of the significant drought and fire-tolerant C^4 grass cover, and 'forest' because of the relatively closed cover of the tree canopy.

In this thesis, the precise term 'dry dipterocarp forest' will be used throughout.

2.2 Vegetation structure and dry dipterocarp forest types

Although there are many common characteristics defining in general 'savanna forest' in Southeast Asia, there exists a range of savanna forest types which, although they exhibit much of the essence of Schimper's description, vary markedly in their structure and floristic composition. It is important to understand these variations, for they may significantly affect the nature of the fire regime which occurs, and in themselves, they are, of course, partly the products of this fire regime. Important factors involved here are the openness of the canopy; the density, height and nature of the ground cover; the presence and absence of rocky outcrops; the presence and absence of a shrub layer; and the balance between leaf litter and ground cover, among many other factors.

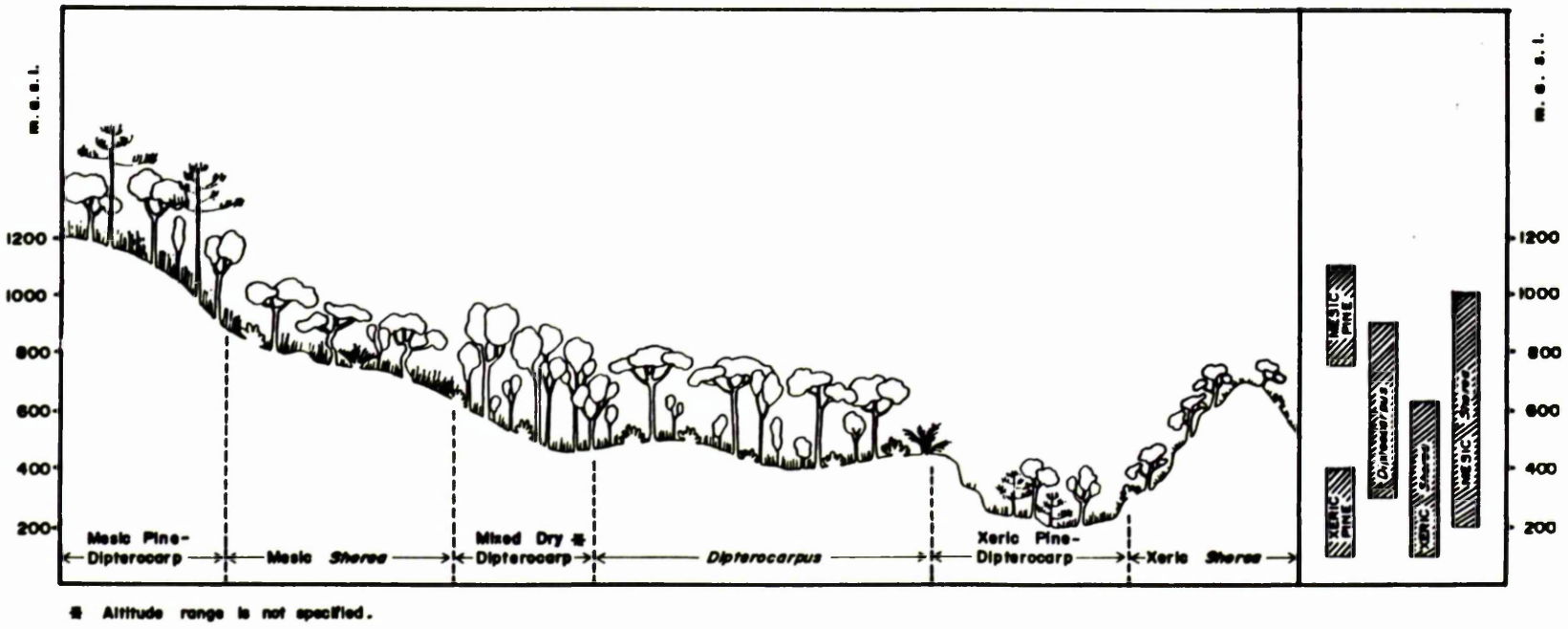
Many attempts have been made to classify, in one way or another, the different types of dry dipterocarp forest occurring in mainland Southeast Asia, the most recent and detailed work being biased towards Thailand, because of the difficult political situation in Indochina and Burma during the past few decades. Various methods have been employed in developing these classifications. Many are based essentially on simple observations, while others use systems like the continental European techniques of the Zürich-Montpellier School of Phytosociology (e.g. Stott 1976), or North American methods of ordination and gradient

analysis (e.g. Bunyavejchewin 1983). The somewhat different results achieved in these studies do not only reflect the different methods and interpretations employed, none of which is fully satisfactory in itself, but also the inadequate sampling and choice of site. The highest number of sampling plots used was sixty 10 x 10 m relevés (Stott 1976), which is not quite sufficient to cover the whole of Thailand.

While none of the work done can be said to be fully comprehensive, it is still interesting to see how well the results can be correlated, at least at a very rough scale (see Table 2.1), with a biogeographical change in the dominant *Dipterocarpus* species from *D.tuberculatus* Roxb. in the west to *D.intricatus* Dyer in the east of mainland Southeast Asia.

Looking at Table 2.1, dry dipterocarp forest can be arranged into four main associations: the *Shorea* associations and the *Dipterocarpus* associations are what is often considered to be the true dry dipterocarp forest (e.g. Khemnark *et al* 1972, Santisuk 1988) or typical '*forêt claire*' (e.g. Blasco 1983); but there are also the Pine-Dipterocarp forest, and the mixed dry dipterocarp forest. It must be stressed that any attempt here to evaluate and rank physiognomy and structure into classes should be taken with some reservation, although it provides a convenient framework within which to work. Much of the difficulty lies in the different aims, and therefore methods, adopted by the different workers. Inevitably, this gives a set of somewhat inconsistent data and information. In most, for example, the estimation of canopy cover percentages is almost absent, and thus my own evaluation of this variable is based mostly on basal area measurements, various descriptions, and my own limited observations. To give some idea, however, Neal (1967) found the percentage canopy cover of dry dipterocarp forest to be between 53% and 77%. Likewise, Sukwong (1974) estimated an average canopy cover of little disturbed moist savanna forest to be around 70%, with 60-80% of sunlight penetrating to the forest floor.

Below is a short description of the general characteristics of the four main associations of dry dipterocarp forest recognized in Table 2.1. Fig.2.3 further illustrates a simplified topographical profile of these associations. The relationship to soils remains little understood, as the available data on the nutrient status of the associations is at present difficult to reinterpret.



* Altitude range is not specified.

Figure 2.3. Simplified topographical profile of dry dipterocarp forest associations (not related to a particular site).

Table 2.1. A general correlation between the main formations of dry dipterocarp forest recognized during the last 50 years for mainland Southeast Asia (for sources, see bibliography).

MANIPUR STATE (Kaith 1936) (Sen Gupta 1938)	BURMA (Champion 1936) (Edwards 1950)	THAILAND (Ogawa *et al* 1961)	THAILAND (Sukwong 1974,1982)	THAILAND (Stott 1976)	THAILAND (Bunyavejchewin 1983) (also Kutintara 1975)	INDOCHINA (Laos, Kampuchea, Vietnam) (Vidal 1960)	INDOCHINA (Laos, Kampuchea, Vietnam) (Legris & Blasco 1972)	PHYSIOGNOMIC STAGES (Blasco 1983)
mesic		mixed savanna forest	mixed dry dipterocarp forest	*Mesopentacmetum suavis* association			*transition entre forêt claires et dense decidues*	dense, semi-deciduous & deciduous forests
			Pine-Dipterocarp forest, mesic var.		Pine-Dipterocarp type			deciduous forests with a moderate tree density
						"classic mix" (*forêt claires floristiquement classiques*)	"classic mix", mesic	typical deciduous dipterocarp open forests
kanyin forest (*Dipterocarpus tuberculatus*)	*indâing* high forests (Upper Burma)				*D.tuberculatus-Shorea obtusa* type	*forêt claire à D.tuberculatus*		
	indâing high forests (Lower Burma)	*D.tuberculatus-D.obtusifolius* phase	*D.tuberculatus-D.obtusifolius* type	*Dipterocarpetum obtusifolio-tuberculati*	*D.obtusifolius-Shorea obtusa* type	*forêt claire à D.obtusifolius*	*forêt claire à D.obtusifolius*	
						forêt claire à D.intricatus	*forêt claire à D.intricatus*	
							"classic mix", xeric	
				Dipterocarpus Pinetum-merkusii association				
	semi *indâing* forest	*Pentacme siamensis-Shorea obtusa* phase	*Shorea-Pentacme* type, mesic var.	*Shoreeto-Pentacmetum siamensis*, mesic var	*Shorea siamensis*, medium tall sub-type	*forêt claire à P.siamensis*	*forêt claire à P.siamensis*	(most typical and most extensive)
			[Pine-Dipterocarp forest, xeric var.]					
					Shorea obtusa, medium tall sub-type			
	indâing scrub forest	*P.siamensis-Shorea obtusa*, xeric form	*Shorea-Pentacme* type, xeric var.	*Shoreeto-Pentacmetum siamensis*, xeric var.	*Shorea obtusa*, scrub sub-type			
					Shorea siamensis, scrub sub-type			
xeric	west							east — close / open

Figure 2.4. Some associations of dry dipterocarp forest.

Fig.2.4a. Very open *Shorea* association, dominated by the grass *Chrysopogon orientalis* A.Camus.

Fig.2.4b. Mesic *Shorea* association. The red flower in the left foreground is a ginger *Costus* sp.

Fig.2.4c. *Dipterocarpus* association.

Fig.2.4d. Pine-Dipterocarp association.

Fig.2.4e. Mixed dry dipterocarp association.

1) The *Shorea* associations

These associations include the semi-*indaing* and *indaing* scrub forests of Burma, all the *Shorea-Pentacme* types of Thailand, and the *forêt claire à Pentacme siamensis* of Laos, Kampuchea and Vietnam (Fig.2.4a,b). The tree canopy is dominated by either one or both of the leaf-shedding dipterocarps, *Shorea obtusa* Wall. and *Shorea siamensis* Miq.(syn. *Pentacme suavis* A.DC., and *Pentacme siamensis* Kurz). In some cases, the two species may form nearly pure stands.

Mesic and xeric variations have been distinguished. Both variants, however, are light and open forests, comprising chiefly tree and ground layers, though a shrub layer can also be present, particularly in Bunyavejchewin's (1983) '*Shorea siamensis* type'. The mesic variant consists of 2-3 tree strata, with the upper canopy reaching 18-25 m in height. The xeric variant is 1-2 storeyed, the trees often possessing crooked boles and rarely growing above 15 m; the crown cover is normally below 60 %.

Ground cover is largely grasses or pygmy bamboo, which grow in an almost continuous layer in the mesic variant. Dense, tall *Arundinaria* spp are particularly characteristic of this form, making it especially susceptible to hazardous fire, where fireline intensity can be as high as

>3000 kW m^{-1} (Sathirasilapin 1987). Other important grasses are *Eulalia* spp, *Themeda* spp, *Heteropogon* spp and *Imperata cylindrica*. *Phoenix acaulis* Ham., *P.humilis* Royle. and *Cycas siamensis* Miq. are common, and some epiphytes and orchids can be found in Bunyavejchewin's (1983) '*Shorea siamensis* medium tall sub-type', e.g. Loranthaceae, *Dendrobium* spp, and *Cymbidium pubescens* Lindl.

The xeric variant generally has a thin, discontinuous grass cover, although *Apluda mutica* L. can be quite dense at some sites. Fire also occurs annually in this form, but it is likely to be less intensive and less wide spread than in the mesic variant. Indeed, fire is often rare at very poor sites, which lack a significant cover of grasses and herbs (Legris & Blasco 1972). Tree seedlings are rather inhibited in both variants. This is probably due to a combination of many factors, such as fire, moisture stress, rocky soils, poor nutrient status, and competition from grass.

On the whole, the *Shorea* associations form the most xeric, most open, and floristically depauperate of all dry dipterocarp forests. They tend to occur on dry ridges and gentle-to-steep boulder-strewn slopes from 130 m.a.s.l. to just over 1000 m.a.s.l., with the mesic variant occupying a higher elevation range of 180-1040 m.a.s.l., while the xeric variant tends to be found from 130-660 m.a.s.l.

The soils are shallow, very stony, and belong to the Red-Yellow Podzolic group. They are mostly sandy loams over sandstone, granite, shale, or quartzite parent rock, although the soils in the mesic variant are comparatively deeper, and this form is occasionally found on clay loams. Laterite forms a hard iron pan in the xeric variant. Rocky outcrops are common.

2) The *Dipterocarpus* associations

This group includes the *kanyin* forest of Manipur state, the Burmese *indaing* high forests, all of Thailand's *Dipterocarpus tuberculatus-D.obtusifolius* types, the Indochinese *forêt claire à D.tuberculatus, à D.obtusifolius*, and *à D.intricatus*, and perhaps the 'classic mix' as well (Fig.2.4c). Generally the forest is dominated by one of the following *Dipterocarpus* spp: *D.tuberculatus* Roxb. and *D.obtusifolius* Teijsm.ex Miq. are both found in India and Southeast Asia, though the former seems to be more important in the west and less so in the east, and *D.intricatus* Dyer, which generally occurs eastwards from northeast Thailand, Laos and Kampuchea. These forest types have a higher number of accompanying tree species than the *Shorea* associations, and only rarely does any one of the

Dipterocarpus spp form a pure stand.

These are truer forest types, with closer and larger trees than in the *Shorea* associations. Usually they are two-storeyed, but they can be three at the very best sites, and only one where heavily coppiced. A shrub layer may occur in some cases. Top canopy trees range from 15 to just over 30 m in height, though they can reach 40 m on a good site with deep, well-drained soils (Bunyavejchewin 1983).

The ground cover is more or less continuous, with grasses and herbs. The grasses are dense and of similar species to those in the *Shorea* associations, such as *Imperata cylindrica, Apluda mutica, Heteropogon* spp, *Themeda* spp and *Arundinaria* spp, but they are more mixed, with a higher proportion of herbs and seedlings, which probably make any fire less intensive. Around Khao Nang Rum Research Station in Huai Kha Kheng wildlife sanctuary, west Thailand, *Heteropogon* spp are more widespread in the *Shorea* associations, while *Apluda mutica*, is often more pronounced in the *Dipterocarpus* types. This is significant because *Heteropogon* spp are known to burn appreciably better and earlier in the dry season than *Apluda mutica*, even in the same stand (see Chapter 6). Tree seedlings are also more numerous in the *Dipterocarpus* associations than in the *Shorea* associations, and often they not only survive, but actually remain green after the fire has passed through (Ogawa *et al* 1961). Some large climbers are present, such as *Spatholobus parviflorus* Ktze. Epiphytes and orchids can be abundant, especially Loranthaceae. Other common non-grass plants are *Cycas siamensis*, members of the Zingiberaceae and the Leeaceae, and *Elephantropus scaber* L.

The *Dipterocarpus* associations are found on sandstone, usually on flat and gently sloping land. At high elevations, they occur on ridges, on moderate slopes, and occasionally on steep slopes. In the lowland areas, the soil is often waterlogged during the wet season. In terms of altitude, they range from 300-900 m.a.s.l., and sometimes occur over 1000 m.a.s.l., but they are most widely found between 500 to 850 m.a.s.l.

Soils are deep, sandy loams to clay loams which tend to be acidic, often lateritic, soils of the Red-Yellow Podzolic group. On the whole, they are the deepest and the least stony soils of all the dry dipterocarp forests. Also, except for the mixed dry dipterocarp forest, the soils of the *Dipterocarpus* associations are normally the richest in organic matter.

3) The Pine-Dipterocarp association

This forest type is found mostly on ridges and mountains over

750 to 1100 m.a.s.l. (Fig.2.4d), but some examples occur between 100-400 m.a.s.l. on old river terraces and plains, which are often flooded. It is usually a two-storeyed formation, although at high elevations, *Pinus merkusii* Jungh.& de Vriese. and *Pinus kesiya* Royle.ex Gordon can form dominant emergents above other associated species, such as the hill evergreen members of the Fagaceae, as well as *Dipterocarpus tuberculatus, D.obtusifolius* and *Shorea obtusa*. Stott (1976) and Santisuk (1988) see most examples of this forest type as secondary formations that are encouraged by fire, representing the advance of the dry dipterocarp forest into former hill evergreen and pine forest. Thus, this formation tends to be ecotonal in character, combining elements of the high hill evergreen forests with the basic character of a dry dipterocarp woodland. At low elevations, *Pinus merkusii* grows to the same height as other dominant species, such as *Dipterocarpus intricatus* in Northeast Thailand.

Stand density and basal area cover range widely in this forest type. At best, it is denser than the *Dipterocarpus* associations, with some odd *Pinus merkusii* growing possibly as high as 40 m, but on very dry sites it can be more open than the most mesic of the *Shorea* associations. Often occurring on rocky slopes, the ground cover is generally sparse and open, and fire can be infrequent at some sites. Important grasses are *Eulalia* spp, *Heteropogon* spp, *Sorghum* spp, *Themeda* spp, and *Imperata cylindrica*. Except in Bunyavejchewin's (1983) '*Dipterocarpus-Pinus kesiya* sub-type', epiphytes and orchids are abundant, particularly *Dendrobium* spp, *Vanda* spp, and *Dischidia* spp. Lichens, especially *Usnea* spp, are also common, and *Phoenix acaulis* is characteristic.

4) Mixed dry dipterocarp forest

This forest type is the most mesic formation, and it is not always considered to be 'savanna forest' (Legris & Blasco 1972, Blasco 1983, Fig.2.4e). It is an ecotonal community between dry dipterocarp forest and the monsoon forest (also known as mixed deciduous forest, or 'tropical moist deciduous forest' after Santisuk 1988), particularly where it occurs on limestones. Stands consist of a wide range of species with no distinct dominant, except perhaps, the non-tomentose variant of *Shorea siamensis*, formerly called *Pentacme suavis* A.DC. (Stott 1976). *Shorea obtusa, Dipterocarpus tuberculatus* and *D.obtusifolius*, and other common savanna forest species, are still abundant, but there are also many species that are usually only common in monsoon forest, such as *Mangifera caloneura* Kurz.

The mixed dry dipterocarp forests are usually 2-3-storeyed,

with top canopy trees growing well over 20 m, and there are normally some low shrubs. Grasses, cycads, herbs, and seedlings form a continuous ground cover. These forests occupy more mesic sites than the other dry dipterocarp forest associations, where fire plays a relatively minor role in the forest ecology. Indeed, seedlings often survive low fireline intensities with their leaves undamaged (Ogawa *et al* 1961). This association occurs on stony, sandy loams to sandy clay loams, on plains and gently undulating lowlands, and often on east-facing slopes. The soils contain higher organic matter, and have a higher cation exchange capacity than in any other association of dry dipterocarp forest.

2.3 Origin and ecological status of savanna forest

There are several different theories concerning the origin and ecological status of the savanna forests of Southeast Asia. As already apparent from earlier comments, three key factors are clearly associated with the occurrence of dry dipterocarp forest, namely climate, edaphic factors, and certain anthropogenic factors. Opinions differ markedly, however, on the relative importance of these factors in the maintenance of this forest formation.

All the dry dipterocarp forests of Southeast Asia are found within a monsoonal regime with 5-7 months distinct dry season, starting from October or November until April, May or June. Such areas fall into Köppen's *Aw* or 'tropical savanna climate' (Mizukoshi 1971), but the formation also occurs in regions with an *Am* (tropical monsoon) climate, where other factors, such as geology and soils, control its spread.

Annual precipitation ranges from 800-2000 mm, but the dry dipterocarp forest occurs mostly in areas with 1000-1500 mm annual rainfall (Smitinand 1962, 1977; Stott 1988a), and, unlike elsewhere in the tropics, no savanna formation is generally found in a drier regime with a lower rainfall and longer dry period (Blasco 1983). The dry dipterocarp forest is essentially a lowland formation, rarely growing above 1000 m.a.s.l., and it barely exceeds the latitude 20°N (Smitinand 1962). Thus, it is warm throughout the year, with daily maximum temperatures always above 20°C. The mean temperature of the coldest months, January and February, is over 15° C, with the absolute minimum temperature usually not below 8° C.

This is more or less a perfect fire climate, with enough moisture to support abundant, thick growth of ground flora during the rainy season, and a rainless period long and warm enough to dry and prepare the ground fuel for ignition. Fire is, therefore, a very common phenomenon, occurring annually on many sites, biennially or less

frequently on others. In some places, dry dipterocarp forest is even burned twice in certain years. Most of these fires are started by humans (Mather *et al* 1978, see Section 1.5.1), who also disturb the dry dipterocarp forest through cutting and the grazing of livestock. It is highly likely that such practices are of some antiquity, dating back even before the earliest known Neolithic communities, which may be as old as 7,000-10,000 b.p. (Gorman 1970, Higham 1989), and these practices have selected a community that coppices well and is fire resistant to certain levels of burning. Hence, the significance of the anthropogenic role in savanna forest ecology cannot be underestimated.

Finally, the dry dipterocarp forest is also associated with poor, dry, and acidic lithosols or soils of the Red-Yellow pozolic group, which often occupy steep rocky slopes.

All workers on Southeast Asian savanna forests recognize the importance of these three intricately associated factors, but their opinions vary as to which is, or are, the key in maintaining forest stability. The French, working mainly in Indochina (Laos, Kampuchea, Vietnam), have tended to see the 'open forest' as a sub-climax community that is stabilized by the influence of regular burning (e.g. Rollet 1962, 1972; Legris & Blasco 1972; Blasco 1983). On the other hand, the British, working largely in Burma, regard dry dipterocarp forest as essentially an edaphic or topographic climax (e.g. Barrington 1931, Champion 1936, Edwards 1950), although they acknowledge that certain forms are stabilized by fire in some regions. And, lastly, many workers in Thailand tend to view dry dipterocarp forest as a climatic climax, edaphic climax and anthropogenic climax all at one and the same time (e.g. Stott 1976, 1984, 1988a,b; Santisuk 1988; Sukwong & Sangtongproaw, pers.comm.).

The French view is well exemplified by Blasco (1983). To him, different types of dry dipterocarp forest represent a gradient of five regressive physiognomic stages from relatively dense, closed forest (stage A) to savanna grassland (stage E). He suggests that the Southeast Asian dry dipterocarp forest is largely a secondary community that is derived from moister forest formations, such as the monsoon forest and the dry evergreen, or tropical semi-evergreen, rain forest. The argument is that all the dominant tree species in savanna forest are not unique to it, but also belong to the moister formations. These species have wide ecological ranges and reproductive strategies that allow them to withstand drought, fires, and adverse edaphic conditions that often result from regular burning.

Thus, as Blasco sees it, the more disturbed a community, the

more open and the simpler floristic structure it will have. Fire protection, on the other hand, reverses the process and allows the build-up of a greater density of woody species. However, he finds that at stage C, which represents the most extensive "typical deciduous dipterocarp open forests" (see Table 2.1), there is actually "no clear evidence of a progressive dynamism of trees leading to more closed ecosystems (stages B and A)...stage C appears to be in a state of dynamic equilibrium, resulting from the combined effects of natural environmental factors and annual burning" (Blasco 1983:177).

In Burma, the stability of dry dipterocarp forest became even more apparent after some 30-40 years of general fire protection from 1874 to 1914 (Barrington 1931, Champion 1936). Such measures had no appreciable effect on the *indaing* forest (*Dipterocarpus tuberculatus* forest) in the lower half of Burma, although it encouraged an evergreen undergrowth in the north, which prevented the reproduction of *in* (*D.tuberculatus*), turning the consociation to a moister type. Throughout Burma, however, on very shallow sandy soils, particularly those on steep slopes and dry ridges, *indaing* scrub forest is found to be a stable association, controlled chiefly by soil (Champion 1936).

With this discovery, the old theory of climatic climaxes and edaphic sub-climaxes is no longer applicable. The British workers of the period, therefore, are inclined to regard dry dipterocarp forest as mainly an edaphic climax, except for, of course, the northern Burma *indaing* forest, which Barrington (1931) sees as 'a preclimax stabilized by annual fires', thus partially sharing Blasco's (1983) view. But, otherwise, Barrington's study of Burma's deciduous forests led him to go as far as proposing that, perhaps, "soil controls vegetation to such a degree that every climax is more or less edaphic" (Barrington 1931:26).

Champion (1936:170), in contrast, is careful to describe *indaing* high forest as "a very stable preclimax under existing conditions with periodic burning even if it is not the climax on these light soils". And, like Blasco, he regards semi-*indaing* forest as a probable successive stage to the denser *indaing* high forest, but , nevertheless, he classes all Burma's savanna forests under 'subsidiary edaphic types of dry tropical forest'. This classification is also followed by Edwards (1950), who further elaborated the various forms of *indaing* forests, with topographic as well as edaphic climaxes within the general climatic regime.

Stott (1988b:346), on the other hand, argues that "fire is endemic and that the [present] formation is largely a fire climax spread

from edaphically controlled communities into adjacent and less fire-resistant forest types, but only... within the area with a fire-inducing climate". There is now sufficient evidence, based on pollen core analyses, to suggest strongly that such a drier, fire-inducing climate prevailed over much of equatorial Southeast Asia during the late Quaternary glaciation (Flenley 1979, 1982). It is thus possible to surmise that a more extensive area of seasonal lowland forests and savanna then covered a greater part of the Sunda shelf area when sea level was 180 m lower than the present day (Whitmore 1984).

As ice retreated and the monsoon re-established itself around 10,000 years ago, Stott (1988b) speculates that savanna forest contracted to the topographic and edaphic 'core' community, which he thinks to be the stunted *Shoreeto-Pentacmetum siamensis* association (Stott 1976), which is comparable to Champion's (1936) soil-controlled *indaing* scrub forest. Stott (1984) observes that this association, which characterizes naturally steep and stony slopes on very shallow soils, is unlikely to have been cleared for agriculture. This argument tends to support his belief in the existence of dry dipterocarp forest before Neolithic times, when humans, with the aid of fire and the axe, began the spread of dry dipterocarp forest into the more fire-sensitive associations. The savanna forest thus created is a sub-climax community maintained by fire. The boundary with less fire-prone, moister forest types, such as the dry evergreen forest of Korat province, Thailand, can be very sharp, with virtually no ecotone at all, except a narrow bamboo border of *Gigantochloa albociliata* Munro. (Sukwong 1976, Stott 1988b). Unless stabilized by topographic factors, such as streams and sharp changes of slope, this boundary will migrate, depending on the degree and frequency of the fires.

Stott (1988a:197) concludes that "the old arguments.. about whether savanna forest is a climatic, edaphic or anthropogenic climax become redundant. The savanna forests of mainland South East Asia are clearly all three at one and the same time" with "the same form being produced by different processes under different conditions" (Stott 1988b:346). Other workers in Thailand share a similar view (e.g. Santisuk 1988; Sukwong & Sangtongproaw, pers.comm.).

In virtually all theories, however, fire clearly plays an important role in the ecology of the savanna forest.

2.4 The ecological role of drought and fire in dry dipterocarp forest

2.4.1 Implications for vegetation and soil

Drought creates a long period of moisture stress, and in dry dipterocarp forest this is accompanied by high air temperatures, which are usually followed by fires. During such periods, the rate of evapotranspiration exceeds the rate of precipitation (Stott 1984). This essential dryness is further exacerbated by the low water-holding capacity of most dry dipterocarp forest soils. This moisture regime is one of the factors that inhibit vegetation growth, giving dry dipterocarp forest its open character and overall low stature and comparatively lower biomass than most of the other forest formations in mainland Southeast Asia (Ogawa *et al* 1965, Sabhasri and Wood 1967).

Dry dipterocarp forest trees and shrubs, however, have developed several xeromorphic characteristics which minimize water loss so well that, in his controlled experiment on the seedlings of *Pentacme suavis* (syn. *Shorea siamensis*), *Dipterocarpus intricatus*, and *Pterocarpus parvifolius* Pierre (syn. *P.macrocarpus* Kurz), Sangtongpraow (1982) found that reduced soil moisture had no appreciable effects on the height growth of the first two species, which are the more characteristic of dry dipterocarp forest. *P.suavis*, in particular, was found to show no significant reduction in its leaf area and biomass under soil moisture stress, making it the most drought tolerant of the three species.

The xeromorphic characteristics of dry dipterocarp forest trees are, for example, densely tomentose leaves and terminal buds, thick bark, and of course, leaf shedding. While *Pentacme suavis*, in its most common association, has tomentose leaves on one side only, Stott (1976) finds that, in the most xeric sites of the *Shoreeto-Pentacmetum siamensis* association, *P.suavis* var. *tomentosa* has hairs on both sides of its leaves, whereas the species is virtually glabrous in the more mesic *Dipterocarpetum obtusifolio-tuberculati* association (see also Smitinand 1968).

Likewise, the phenomenon of leaf-shedding, which generally occurs from November to March, varies between sites in its degree and timing, depending on the moisture regime. In my own study site in West Thailand, leaf-shedding tends to be one month later than in Northeast Thailand. It also varies between species, although the six dominant dipterocarp species of the dry dipterocarp forest are all deciduous to some extent (Santisuk 1988), and form part of a very distinctive ecological group within the Dipterocarpeceae.

A number of studies on the phenology of dry dipterocarp forest trees at Sakaerat research station in Korat province, northeast Thailand (e.g. Nalamphun *et al* 1969, Wongpaibul 1974, Sukwong *et al* 1975), have shown that *Shorea obtusa* tends to be slower in shedding its leaves than *S.siamensis*, although by the end of January, up to 90% leaf fall of both tree species is normal. In some years, depending on the nature of the wind direction and wind speed in February, the remaining leaves are then shed by the end of March. However, on moister localities, such as the area near to a bath house on the research station, leaf shedding was much less, and trees remained relatively green until February, whereas most other individuals away from this location had completed their defoliation (Nalamphun *et al* 1969). It is also known from elsewhere, as in the north of Thailand, that the degree of deciduousness and the period of leaflessness of dry dipterocarp forest trees vary considerably with soil moisture content (Santisuk 1988).

The time of considerable leaf-shedding has a direct influence on the time of the main period of forest fires (although the understanding of fire timing is still confused, and this will be discussed more fully in Section 3.2). While leaf litter provides a carpet of natural tinder on the forest floor which will sustain an extensive burn, the leafless canopy is at its thinnest, thus allowing in more direct sunlight and raising ground temperatures to dry and prepare the fuel for ignition (see Section 5.3).

Dry dipterocarp forest fuels include the withered ground cover which, during the period of drought, lies dormant in some form or another giving fire tolerance. The therophytes (the annuals) simply store seeds in the soil, or else they are dispersed from elsewhere. The hemicryptophytes (e.g. the dominant grasses, pygmy bamboos) and the geophytes (e.g. ground orchids, such as *Habenaria* spp; members of the ginger family, Zingiberaceae), both of which are found abundantly in dry dipterocarp forest, have their perennating organs either underground or protected at the soil surface by a dense mat of dead matter.

Similarly, some large perennials, such as the dwarf palms of the genus *Phoenix* and the cycad, *Cycas siamensis*, have either short, stubby stems, which are protected from fire by overlapping leaf bases, or possess underground stems (e.g. *Phoenix acaulis*). Having a low humus content of less than 2-4% (Sangtongpraow *et al* 1973, Sukwong 1982), the poor sandy-loam soils of dry dipterocarp forest are effective insulators, so that even a surface temperature as high as 700°C cannot raise the soil temperature at 5 cm depth above 35°C (Sukwong *et al* 1977, Stott 1986).

The thick bark of dry dipterocarp forest trees is also a good insulator, as demonstrated by Stott (1986), who found that bark-surface temperatures of over 350°C fail to raise significantly the temperature in the vital cambium layer behind the bark of trees like *Dipterocarpus intricatus* and *Shorea obtusa*. The thick bark, however, is multi-functional. It not only has a protective role against drought, but also against soil erosion, by increasing the interception rate, with low throughfall and stemflow, when compared with the semi-evergreen forests (Chunkao *et al* 1971).

This feature, though, is likely to have been selected particularly by fire, as may be seen in the difference between the savanna forest form of *Pinus merkusii* found in mainland Southeast Asia and the less fire-adapted form found in Sumatra, the former having a far thicker bark and a seedling 'grass' stage (Cooling 1968; Sangtongpraow 1973; Stott, Goldammer & Werner 1990). Tree torching can occur on specimens where bark is damaged, or as Stott (1988b) has noted, on thinner-barked species, which are only transgressives in the dry dipterocarp forest, such as the hog plum, *Spondias pinnata* Kurz, and *Xylia kerrii* Craib & Hutch. (syn. *X.xylocarpa* Taub.).

The main tree taxa have two means of regeneration: from underground root buds and from seeds. Dry dipterocarp forest trees tend to produce a large supply of seeds, thus ensuring a significant percentage of germination and seedling survival from drought and fire. In Sakaerat Research Station, the slightly heavy winged fruits of the dominant dipterocarps, which are suitable only for local wind dispersal, tend to fall mostly in February and March, during and after the peak period of forest fires. They germinate on the burned soil at the start of Southwest monsoon. On the other hand, trees with thick seed coats, such as *Irvingia malayana* Oliv.ex A.Benn., *Lithocarpus* spp, *Quercus kerrii* Craib and *Sindora siamensis* Teijsm.ex Miq., tend to drop their fruits in November and December before the fires (Sukwong *et al* 1976). It is sometimes thought that fire may be beneficial to their germination (e.g. Stott 1988b), but detailed study is yet needed.

The key dry dipterocarp forest trees have root collars with numerous root buds on both the tap root and lateral roots. Sprouting potential varies in different species, but generally the bigger the girth of root collar, the higher the number of sprouts and their growth (Sangtongpraow 1985). In his study of *Shorea siamensis* and *S.obtusa* in Sakaerat, Sangtongpraow (1985) found that a seedling sprout must reach a height of over 170 cm, with a girth of 10 cm, and a bark thickness of

0.6 cm, in order to resist high fireline intensities from ground cover burns of *Arundinaria pusilla*, 50-170 cm tall. This type of fuel gives the most extreme fire (Stott 1986), thus it is likely that the shortest seedling able to survive a less fierce leaf litter or lower ground cover burn is of a lower height.

Wacharakitti *et al* (1971) found that it takes an average of 3-4 years for most dry dipterocarp forest seedlings at Mae Huad, Lampang province in the north of Thailand, to reach over 170 cm without disturbance from fire. In the case of *S.siamensis*, most take two years, and some even grow beyond such a height within one year. *Dipterocarpus tuberculatus* is the slowest. This species often dies back after a few years, but, given time to store food and a good monsoon, it will resprout to a height and size that will allow it to resist both drought and fire.

This implies that more than one year of fire-free interval is needed to ensure successful regeneration of many members of the dry dipterocarp community. Studying the effects of different fire frequencies on the vegetation of a *Shorea* association at Sakaerat Experiment Station, Suthivanit (1989) found that, after 4 years of observation, there was no seedling growing into a sapling (height >1.30 m, dbh ≥10 cm) in the plot burned annually, compared to 71% growth in the protected plot, and 20%, 33%, and 53% in plots burned every 2, 3 and 4 years respectively. But although the growth rate is much impaired by fire, the mean height of the *Shorea obtusa* seedlings in the annually burned plot still increased, albeit by very little, at 1.8 cm yr^{-1}, compared to the 3.9 cm yr^{-1} growth rate in the protected plot.

Furthermore, the spatial pattern of much dry dipterocarp ground cover would, in itself, aid regeneration. From my own observations, dry dipterocarp forest seedlings often grow in small clumps, where a low or an average fireline intensity sometimes fails to reach the inner individuals. Such patchy burns provide a mosaic of small fire-free areas. In reverse, the clump distribution is itself a reflection of patchy burning.

Generally, species diversity was maintained in all the plots burned by Suthivanit (1989), while there was a higher increase in tree seedling and herbaceous species in the control area. Seedling density, however, increased in both the annually burned plot and control plot. Shrub density decreased under both treatments, with species composition being maintained in the annually burned plot and reduced in the protected area. As seen elsewhere (e.g. Africa), 4 years of fire protection caused a decrease in grass density by 30%, while in annually burned plots, grass

density increased by 11%.

Vegetation recovers quickly, often within two weeks after fire, even before the onset of the Southwest monsoon. Stott (1988b) found some seedlings to sprout as high as 50 cm within one month after the above ground part was destroyed, either by fire or cutting. Coupled with the releasing of surface nutrients, fires seem to induce growth, leaf flushing, and in some species, flowering, as in the case of *Imperata cylindrica* (see Section 7.3.1). Nitrogen fixing leguminous species tend to grow abundantly in the burned areas, thus compensating for the loss of nitrogen on ignition.

Little research has been done on the effects of fire on dry dipterocarp forest soils. Sukwong and Dhamanitayakul (1977) found overall nutrients to be less in repeatedly burned (annual or more frequent) areas, while Boonplian (1985) found soil nutrient status to reduce after one year following an extreme fire in a recently derived *Imperata cylindrica* grassland. Repeated burning also increases erosion up to 3-32 times (Komkris *et al* 1969), particularly on steep slopes of >7°, although a one off burn after 5-6 years fire-free interval can have very little effect, or yield even less erosion than in an unburned area, due to the well-developed ground cover layer. Generally, however, fires maintain the poorness of savanna soils, with their low humus content, and so help to maintain the essential insulating property of the soil.

2.4.2 Implications for animals

With its significant grass coverage, dry dipterocarp forest is further an important grazing source for a wide range of herbivores. Herds of livestock are often let to graze in dry dipterocarp forest, although, at least until very recently, pastoralism has not been important in the Thai rural economy. If this trend changes, there would be an urgent need for research on the interaction of grazing and fire on savanna resources in Thailand.

Wild herbivores, such as barking deer (*Muntiacus muntjak* Zimmermann), banteng (*Bos javanicus* D'Alton), gaur (*Bos gaurus* Lambert), the very rare kouprey (*Bos sauveli* Urbain), Indian elephant (*Elephas maximus* L.), siamese hare (*Lepus peguensis siamensis* Bonhote), and the sambar deer (*Cervus unicolor* Kerr) frequent dry dipterocarp forest. The last visits dry dipterocarp forest at dusk, dawn or night, although it tends to stay in the dense semi-evergreen forest during the day time (Lekagul and McNeely 1977). Likewise, few mammals and herpetofauna are primarily endemic to the dry dipterocarp forest. In the dry season, the

large herbivores tend to retreat towards the moister formations or along water courses (Prayurasiddhi, pers.comm.), but the dry dipterocarp forest still remains important, particularly after fire has induced nutritious new growth for feeding, although indirectly the animals become more vulnerable to hunters at such a time, through increased through-forest visibility (Neal 1967).

Drought and fire, undoubtedly, dictates the pattern and size of habitat usage by animals. Ngampongsai and Laohajinda (1988) found population and species numbers of both predators and prey in Sakaerat to reduce noticeably in the hot season, which commences around February, in the middle of the dry period. In Huai Kha Khaeng Wildlife Sanctuary, West Thailand, fire occurrence can force small cats and civets to increase considerably the activity radii and shift their home ranges into occupied territories in the adjacent dry evergreen forest (Rabinowitz 1990a,b). More research on the effects of different fire regimes on animal population dynamics is, therefore, much needed (Nakhasathien & Stewart-Cox 1990).

A preliminary survey in Huai Kha Khaeng Wildlife Sanctuary by Prayurasiddhi *et al* (1988) found that, of *c.*600 species recorded in the sanctuary, only 51 species (8.5%) are estimated to benefit from forest fire occurrence, largely through improved feeding habitats. Many of these are animals common or characteristic to dry dipterocarp forest, such as the butterfly lizard (*Leiolepis belliana rubritaeniata* Mertens), several species of vulture and falcon, and a few species of drongo which fly directly into forest fire smoke to catch fleeing insects (pers.obs.). Otherwise, most animals which do not benefit or are damaged by fire, learn to adapt or to minimize the risk.

Personal observation also indicated that many take refuge underground, such as the burrow-nesting birds, like the green bee-eater (*Merops orientalis* Latham), some snakes and rodents, as does the butterfly lizard. Others, including the lineated barbet (*Megalaima lineata* Vieillot), the black-headed oriole (*Oriolus xanthornus* L.), and some species of small squirrels, nest some 15-20 m high up in the trees, although several species nest quite low in tree holes at 6-8 m high, such as the collared falconet (*Microhierax caerulescens* L.) and the common golden back woodpecker (*Dinopium javanense* Ljungh.). Most remarkable, though, is the black drongo (*Dicrurus macrocercus* Vieillot) which not only nests openly on branches 8-10 m above ground, but stays incubating her eggs even when a smoky fire burns almost directly below. The ungulates and other fast-moving mammals use their speed to escape fire. The

slow-moving are more susceptible, like some species of land turtle (Petchkong *et al* 1989). However, in denser stands, as in the monsoon forest or a dry dipterocarp forest that has been left unburned for several years, swift mammals, like common wild boar (*Sus scrofa* L.) and barking deer, are sometimes trapped and roasted alive (Duangkhae 1987; Muuk, pers.comm.).

Although most adult animals can probably avoid fire, the eggs and the young run higher risks. This is particularly true in the case of ground-nestling species, such as the red jungle fowl (*Gallus gallus* L.) and the green peafowl (*Pavo muticus* L.). Both bird species are more characteristic of monsoon forest, but jungle fowl are often found along the ecotone with dry dipterocarp forest. The main breeding period, from January to March (Nakhasathien *et al* 1987), further coincides with the fire season. These often minimize the risk by nesting near to water courses, and among green undergrowth, such as clumps of seedlings or shrubs, or where there is little dry fuel (Prayurasiddhi *et al* 1988). The red jungle fowl may also lay more eggs after fire has passed through (Nakhasathien *et al* 1987), but certainly, burnt jungle fowl eggs are not uncommon finds in some areas (pers.obs.).

Little is known about the effects of fire on the insect populations, although some species are probably not affected too severely, as certain dry dipterocarp forests are home to a large number of insect-eating bird species, such as members of the woodpecker family, the Picidae (Lekagul & Round 1991). Seed-harvesting ants are abundant. They store a large amount of grass grains at the beginning of the dry season, an act which must help to protect some proportion of grass seeds from direct fire damage. However, decomposer populations, notably the termites, could become limited with repeated burning, through lack of litter and dry grass remains on the forest floor (Holt & Coventry 1990). Nothing is known about fire impact on micro-organisms in Thailand.

2.5 Conclusion

It is thus clear that drought and fire have selected plant and animal species which tolerate, or avoid, the fire stress. Fire helps to maintain dry dipterocarp forest as an open association by limiting successful seedling growth and inhibiting the establishment of less fire tolerant and shade-bearing species, including shrubs. But similarly, the forest itself partly dictates the fire regime. The protective tree bark and the open forest structure usually prevent crown burns, while the horizontal fuel distribution and the annual period of drought allows

regular ground fires to occur. Where edaphic factors are the primary control, however, the role of fire becomes less important. Elsewhere, a change in the fire regime, whether to a greater or lower intensity of fires, will allow other vegetation types to take over.

CHAPTER 3.

ECOLOGY OF FIRE TIMING IN THE SAVANNA FORESTS OF THAILAND

3.1 Previous work and forest management

As shown in Chapter 2, the main lines of fire research so far concerning dry dipterocarp forest have focussed on fire and general forest status, and more specifically, on the relationship between fire and various life forms, with most workers looking at the adaptation, or maladaptation, of certain plant and animal species to fire, and the rate and degree of vegetation recovery after burns (e.g. Sukwong & Dhamanitayakul 1977; Sangtongproaw 1986b; Stott 1986, 1988a,b; Suthivanit 1989; Worseley & Aguirre-Hudson 1991). There is also a range of work covering some aspects of the fuel characteristics of dry dipterocarp forest, such as measurements of litter and undergrowth biomass (e.g. Nalampun *et al* 1974; Paowongsa 1976; Wanussakul 1989; Wayanond, unpublished). Less work has been done on the effect of fire on soils (e.g. Komkris *et al* 1969, Sukwong & Dhamanitayakul 1977, Boonplian 1985), but even less still is known about the impact of fire on many other aspects of the physical environment, except for Sangtongproaw's (1986a) preliminary survey of forest fire smoke in Chiangmai and Chiangrai provinces in North Thailand.

Most of the above studies are, however, small, piecemeal affairs. It is only Sukwong and Dhamanitayakul (1977), and in particular Stott (1984, 1986, 1988a,b), who have compiled in any sense comprehensive syntheses on the role of fire in dry dipterocarp forest (see Chapter 2); they have also pioneered work on the spatial pattern of temperatures in the dry dipterocarp forest fires of Thailand.

Both used types of heat-sensitive paints which undergo irreversible colour changes at given temperatures. Sukwong and Dhamanitayakul (1977) tried to use 'tempilaq' on asbestos strips, but with only limited success, as the colour changes were obscured by the burn. Work by Stott (1986), however, using 'thermocolor' paints on mica pyrometers, confirmed some of the results of this earlier attempt. As described in the previous chapter, Stott (1986) tested the insulating property of the bark of certain dry dipterocarp forest tree species, and the sandy loam soils, by placing the paper-thin pyrometers on and behind the bark in the vital cambium layer, as well as below the ground at 5 cm depth. But above all, he experimented with burns on different fuel types, primarily litter burns and ground cover burns. The former occur where there is a thin

ground cover with a good carpet of leaf litter, and the latter where there is a significant, continuous cover of 50-100% of grasses and other undergrowth.

Stott (1986) found that, with litter burns, the highest temperatures are always at ground-level, with a mean around 400°C, ranging from 250°C (2-3 leaves deep) to 700°C (over 6 leaves deep). Ground cover burns, on the other hand, attain the highest temperatures mostly at 0.5 m, with a mean around 300°C. Most burns did little direct damage to the ecosystem, except for the 'extreme ground cover burn', which feeds on nearly pure stands of grasses and pygmy bamboos, with over a 95% cover, and a height up to 3 metres. This type of burn proved to be a serious management threat where, at 0.5-1 m above the ground, the fire can attain temperatures of up to 900°C, and the rate of spread is more than 3 cm s^{-1} (1.8 m min^{-1}), under slight wind conditions, with a flame length of more than 2.5 m. Stott (1986:357) writes, "Extreme wind conditions will turn this type of burn into uncontrollable wildfire which is capable of igniting logs and trees and which will jump across even wide fire breaks. Unfortunately, the present policy of trying to exclude fire completely from many forest areas is leading to the growth and development of such potentially dangerous stands." He suggests an alternative policy of planned burning.

Stott, however, was not the first to suggest a policy of prescribed burning for Thailand. Mather (1978a,b,c) surveyed the problem of fire control on the Mae Sa watershed, Chiangmai province, North Thailand, looking particularly at potential fire weather data and the rate of fire spread. Despite having found that most fires are human-induced (Mather & Maneeratana 1978), Mather (1978a:1) reasoned that "If the annual rainfall.... was distributed over the whole year and if daily maximum temperatures never exceeded 20°C, it is doubtful if any forest fires would occur in Northern Thailand" and so even though "..complete fire exclusion could be attained... there is a danger in allowing massive fuels to accumulate... that if an accidental fire were to occur, it would be of a very high intensity and would cause serious damage to growing stock before it could be suppressed with difficulty" (Mather & Maneeratana 1978:30). The ineffectiveness of complete fire protection was demonstrated by a major fire which occurred in a 5-year protected stand of dry dipterocarp forest with a pure pygmy bamboo undergrowth, ignited by fire 'spotting' from a roadside burn (Stott 1986).

The total area of dry dipterocarp forest in Thailand surveyed in 1982 was 48,930 km^2, and this comprised 31% of the total forested area

of the country (*Forestry statistics of Thailand*, 1989). Based on three years of records collected by the Forest Fire Control Unit between 1984-1986, the estimated area of dry dipterocarp forest burned ranges from 3,181,155 rai[8] (5,080 km^2) in 1986 to 5,731,564 rai (9,170 km^2) in 1984 (Settarak *et al*, 1987). These statistics suggest that only 10-19% of dry dipterocarp forest in Thailand is burned each year. However, this figure is probably a severe underestimate.

In fact, it is likely that only a small fraction of the burned area was sampled by the Forest Fire Control Unit (FFCU), whereas the total area of dry dipterocarp forest is probably much less than that officially stated. In 1989, the Royal Forest Department (RFD) claimed that there was 28% of forested area left in the whole country. But, in actual fact, this figure includes scrub land and sea water areas within coastal and island national park boundaries. Many people working in the Wildlife Conservation Division in Royal Forest Department feel that 12% is probably a more realistic estimate for the forest-covered area of Thailand (e.g. Nakhasathitti and Prayurasidhhi, pers.comm.).

The general extent of forest fires are well attested by forest travellers and rural residents. In the North of Thailand, there are so many fires that, during March and April each year, smoke covers the entire urban and rural areas of Chiangmai, Chiangrai and Lampang provinces (Sangtongproaw 1986a). The situation is seen to be even more serious if we take into account Newell *et al*'s (1989) report on the Measurement of Air Pollution from Satellites (MAPS), which argues that tropical forest burning rivals transportation and industry as a source of carbon monoxide (and hence carbon dioxide), making it a major contributor to the phenomenon of 'global warming'. Couple this with the problems of soil erosion and nutrient loss caused by repeated burning in many areas (Komkris *et al* 1969, Sukwong & Dhamanitayakul 1977), it is obvious that, although the dry dipterocarp forest is well adapted to certain levels of fire intensity and frequency, there is presently too much fire in the formation. And since the current policy of complete fire protection has proved unrealistic, and at times downright dangerous, there is clearly a need for a new management scheme of forest fire control, involving some degree of prescribed burning.

In order to prescribe burns satisfactorily in the dry dipterocarp forest, for whatever objectives, a better understanding of fire behaviour under various conditions, and of both its direct and

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[8] 1 rai = 1600 m^2 (0.16 ha)

long-term impact on the ecosystem, is urgently needed. This thesis forms part of a general research scheme set up by P.A.Stott to work towards such an understanding, and, in particular, examines some key aspects of the seasonal timing of savanna forest fires, a subject much neglected in all previous studies.

3.2 The problem of the seasonal timing of dry dipterocarp forest fires

The timing of dry season fires has been noted to vary in different areas. Stott (1988b) observed that dry dipterocarp forest fires in the northern region, around Chiangmai province, come comparatively early in the dry season, from December through to February, whereas in the Northeast, around Nakhon Ratchasima (Korat) province, the fires tend to be much later, usually occurring from February to April, or even May in some years. The Forest Fire Control Unit's record of 1985 fires shows similarly varying patterns between different provinces, with fires around Chiangmai lasting through to April and May (Fig.3.1), although there appears to be no distinctive pattern for each region, such as a difference between North and Northeast Thailand (FFCU record, 1986). These, however, are records of fires in all forest types, and not just the fires in the dry dipterocarp forest. They also represent the date of all reported fire events in one particular year, while other workers tend to refer to the main periods of fire occurrence. Sukwong and Dhamanitayakul (1977) find dry dipterocarp forest fires around Nakorn Ratchasima to start generally in January, a month earlier than Stott (1988b) noted.

There is as yet no comprehensive explanation for the occurrence of these varying times of dry dipterocarp forest fires, and it is not known whether there is any cultural factor, or factors, controlling the phenomenon within the natural limits of the general environmental factors. Indeed, to date, little detailed interest has been expressed on the question of fire timing in Thailand, although fuel moisture content, controlled by a range of environmental factors other than rainfall, such as atmospheric temperature and humidity, is generally accepted to be a key factor determining the start of the fire season (e.g. Mather 1978a). Such preparation of the fuel bed has been linked with the time of considerable leaf fall, when the canopy is most open, allowing direct sunlight to dry and heat up the leaf litter and undergrowth (Sukwong & Dhamanitayakul 1977; Stott 1984, 1988b). With respect to Sakaerat Experiment Station, Korat province, Sukwong and Dhamanitayakul (1977) correlated leaf shedding with the peak period of dry dipterocarp forest fires in January

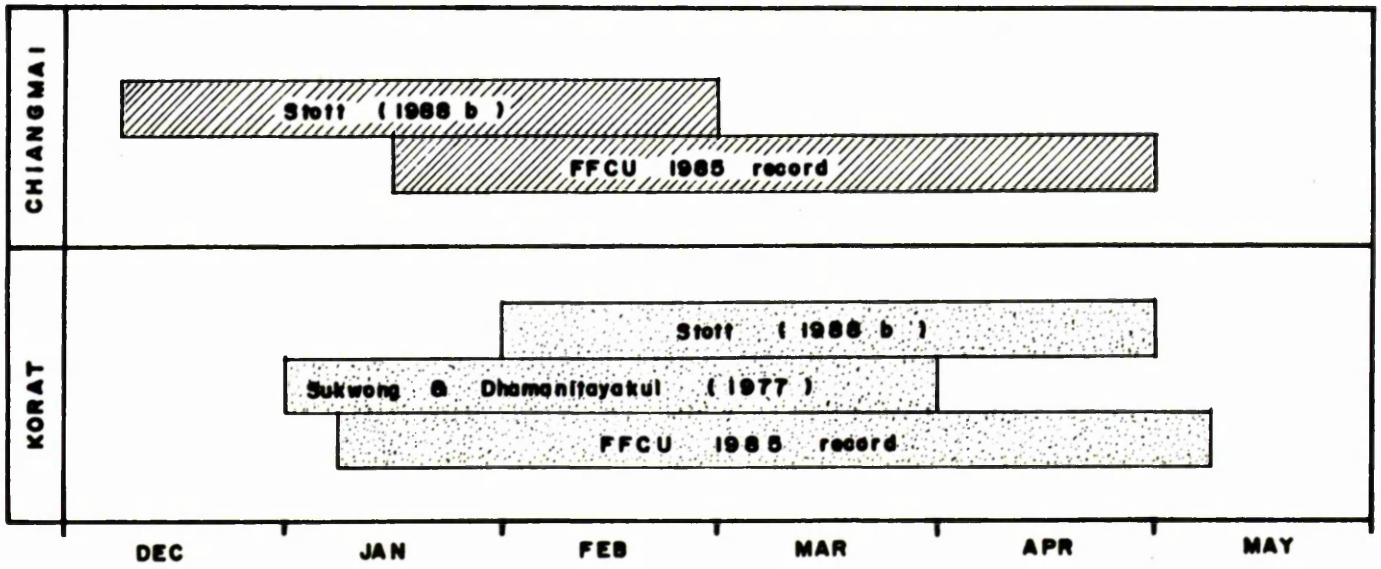


Figure 3.1. Comparison of fire timing observed by different workers in the North (Chiangmai province) and Northeast Thailand (Korat province). (For sources, see bibliography. For FFCU, see under Forest Fire Control Unit, 1986).

and February, while Stott (1984, 1988b) says that there is a period of considerable leaf fall which predates the main period of forest fires by a month or so.

As shown in Section 1.5.1, the potential for lightning fires occurs mostly from March to May, with the highest probability in April, at the end of the dry season, or often the beginning of the rainy season. Thus, prior to the widespread use of human-induced fire, occasional late season burns would probably have been the prevailing fire regime. However, under the present situation, fire timing has shifted so that much of the dry dipterocarp forest in many areas is probably already burned before April, which will have reduced the occurrence of lightning fires. It is also likely that the intensity of pre-human-induced fires was also greater due to lower frequency and, therefore, larger fuel accumulation.

In Thailand, no clear definition has ever been given for the terms 'early' and 'late' burn, but there is a general assumption, both in Thailand and elsewhere, that burns which occur early in the fire season, when fuel moisture content is still high and the average daily temperature still comparatively low, are less intensive than burns which occur later in the season, when fuel is very dry and the average daily temperature is high (e.g. Philips 1974; Mather 1978a,c). Studying the potential fire weather data in Mae Sa watershed, Chiangmai province, from 1976-1978, Mather (1978a) found that the absolute maximum temperature tends to rise from 25° C in January to over 35°C in April or the first week of May, while the absolute minimum relative humidity is at its lowest, around 15%, in the third week of March, while reaching 40% in January and May. He also looked at the diurnal fluctuation of temperature and relative humidity in detail from the first week of January to the first week of May, the period he considers ripe for 'late' burning (with the months from October to December considered as 'early').

Based on his belief that people begin to light fires in the forests when the trend in the daily minimum relative humidity begins to fall below 50%, and the daily maximum temperature begins to rise above 24° C (Mather & Maneeratana 1978), Mather (1978a) calculates the hours of high and low fire hazard for these months of 'late' burns. This shows that the span of time for potential burning increases with the season, from 3 hours in January; 3-8 hours in February; up to 9 hours in March, and 10 hours in April.

But outside Mather's (1978a) work on fire weather data, little serious research has ever been done on the seasonal timing of fire in Thailand, except, perhaps, a preliminary and unpublished study by Surin

Namprasert, who looked at the effects of fire timing on mushroom populations in Huai Hong Klai, Chiangmai province. He found mushroom species diversity to be higher in a control plot, although the quantity (biomass) was noticeably lower than in the burned plots. As the data is not yet analysed, the impact of the different timings of the burns is not yet recorded. Practically nothing, therefore, is known of comparative fire characteristics at different times, or of their ecological impact on the dry dipterocarp forest ecosystem.

An understanding of the seasonal timing of fires is also crucial for proper wildlife conservation. Not only do we need to know about the impact of fire on animal feeding patterns and habitat usage, but also, and perhaps most important of all, we need to know the impact on their reproductive cycle. This is particularly crucial for species which mate and reproduce during the dry season (see Section 2.4.2).

Unfortunately, in this thesis, most of the above questions are left untackled. The present objective is to establish some neccessary basic understanding with regard to the nature of 'early' and 'late' burns, and to present ideas for further research.

CHAPTER 4.

THE RESEARCH SCHEME AND FIELD METHODS

4.1 The research scheme (Table 4.1)

The research aim, in brief, was to investigate the development of fuel characteristics and the resultant fire behaviour over the dry season in the dry dipterocarp forest of Thailand. The impact of the different timings of fire on vegetation and fuel recovery was then assessed over a year.

1) Main experimental plot

The duration of the field research was essentially 13 months, from October 1987 to November 1988. The plan was first to set up a series of 10 m x 10 m permanent study plots, where records of fuel and vegetation characteristics could be monitored monthly during the study period. These plots were then subjected to different timings of burn throughout the dry season, but with at least one plot remaining unburned. The first plot was burned as soon as fire could be sustained, and the other plots were burned subsequently at one month intervals. Experimental burns ceased on the return of the Southwest monsoon, or when it was no longer possible to burn, for whatever reason. In order to compare data on the dynamics of vegetation and fuel recovery after these burns carried out at different times, the plots had to be laid out in the same forest stand, and made as ecologically homogeneous as possible. The plots were established on more or less flat land to minimize unwanted variables. The main forest stand chosen was in a *Dipterocarpus* association, near a research station in West Thailand (see Section 4.5). The site of these permanent study plots is referred to as the '*Dipterocarpus* 1' stand throughout.

Fuel and vegetation were divided into five categories, namely grasses, non-grass ground cover, leaf litter, dead woody fuel, and fine broken matter. The following data was collected monthly for these different categories:

a) internal moisture content;
b) biomass;
c) height of standing fuel and depth of litter;
d) fuel arrangement;
e) ground cover percentage;
f) ground cover density;
g) canopy cover percentage;

h) phenology of both ground vegetation and canopy trees.

The last two sets of data, (g) and (h), were collected because they are directly related to fuel characteristics and plant adaptations to fire. Canopy cover area determines the amount of direct sunlight reaching the forest floor, which dries up the surface ground fuel. Phenology influences fuel accumulation, through the timing of leaf shedding and the withering of some plant species. Flowering and fruiting time further shows their sexual reproduction strategies in relation to fire timing. At the end of every month, the intrinsic values for the ignitability and sustainability of non-woody fuel was also tested. The success or failure was based largely on the internal moisture content of the fuel. This determined the time of year when each fuel type dried out to the point when it could begin to sustain fire.

In addition to the basic monthly data on fuel and vegetation characteristics described above, species composition of the ground cover and its diversity and dominance were also determined. This was done three times, once at the beginning and once at the end of the rainy season, to compare a year's development in each plot. The third time was during the dry season, before the first burn. This was to record the differences in species diversity between the rainy and the dry season.

2) Extension of research

The study of fire behaviour was then extended beyond the main experimental forest stand. At the beginning of the fire season, in early January, when forests are just able to sustain some fires, small trial burns were carried out in many different dry dipterocarp forest stands, to see which could sustain the earliest burns, and with what characteristics. Because the principal aim of the thesis was to investigate fuel characteristics and the resultant fire behaviour in respect to seasonal timing, other variables were kept as constant as possible. Thus, all the burns were set at roughly the same time of day, on flat land, and under low wind conditions. For each burn, basic data on climatic conditions for the burn and fuel characteristics were recorded.

3) Comparative plot

For the rest of the dry season, an area of a *Shorea* association at the same elevation as the permanent study plots (*Dipterocarpus* 1) was also burned at monthly intervals throughout the dry season. This facilitated comparisons of fuel characteristics and fire behaviour between the two most widespread dry dipterocarp forest associations. This *Shorea*

stand will be referred to as '*Shorea* 1' throughout.

4) Fire behaviour

The following measurements were taken for the study of fire behaviour:

a) maximum temperature (°C) at ground level;

b) duration of maximum temperature (s);

c) spatial pattern of temperature (°C);

d) speed of fire spread (cm s^{-1});

e) pattern of fire spread;

f) flame height (m) and frontal fireline intensity (kW m^{-1}).

Measurements (a), (b) and (d) were taken for all the burns; measurements (c), (e) and (f) were only taken in the burns in the main *Dipterocarpus* 1 stand.

5) Additional field work

After the main field study was completed in November 1988, an additional burning experiment on leaf litter was carried out in January 1989. Different leaf litter depths representing patterns of litter accumulation at different times in the dry season were employed. Maximum temperature (°C) at ground level, its duration (s), and the speed of fire spread (cm s^{-1}) were all recorded.

Table 4.1 summarizes the actual data recording done from October 1987 to January 1989. From this it will be seen that burning in the *Dipterocarpus* 1 stand did not begin until the end of February. This was due to an unexpectedly heavy Northeast monsoon at the beginning of February 1988.

4.2 Field methods in detail

In the experiments, three key sets of measurements were taken, namely: an analysis of fire behaviour; vegetation and fuel characteristics; and physical conditions. The methods employed for each of these will now be discussed in detail:

4.2.1 Measurement of fire behaviour

Some objections have been made against the measurement of above-ground fire temperatures, most of all because of the technical difficulties in obtaining adequate accuracy, whether in measured values, or in representive sampling quantity (e.g. van Wagner & Methven 1978, Alexander 1982). Alexander (1982) further feels it to be too troublesome,

MONTH	*Dipterocarpus* 1				*Shorea* 1	Other Stands	NOTE	
1987	monthly			occasional				
Oct Nov Dec	ignitability / sustainability test	fuel / vegetation characteristics	phenology & canopy cover	species count				dry season
Jan				unsuccessful 'early' burn species count	'early burn'	other ground cover burns	FIRE	
Feb				'mid-season' burn	'mid-season' burn			
Mar				'late' burn	'late' burn			
Apr May Jun Jul Aug Sep Oct Nov 1988				species count				
Jan 1989					leaf litter burns	dry season		

Table 4.1: General research scheme (October 1987 - January 1989).

while being quite unneccessary and less useful as a key monitor than some other characteristics of fire behaviour, such as flame height and speed of spread, which are commonly used to formulate 'fireline intensity' after Byram (1959). This measure describes the energy output rate per unit length of fire front, which Alexander (1982:349) considers to provide "the single most valid characteristic of a fire's general behaviour and direct impact on above ground vegetation" that can be simply expressed in one numerical value. Temperature, on the other hand, reflects only part of the heat yeild in forest fuel combustion.

Other workers think otherwise. Hobbs *et al* (1984) and MacLean and Wein (1977) feel that fire temperature is more easily interpreted than values derived using the term 'fire intensity', which they find rather vague. This is, of course, provided that the limitations of the measuring instruments are well known and acknowledged. In my opinion, graphic profiles of forest fire temperatures can give a very useful *visual* impression of fire behaviour, which is readily appreciated by most readers. Although the measures do not represent the total heat yield, they do provide one of the best pictures of heat radiation, which is a different image from the visible fire flame. Further more, measurement of duration of temperature can describe at least one characteristic of fire behaviour that 'fireline intensity' cannot. This is because 'fireline intensity' describes only the energy released within the active fire zone, and does not take into account the duration of combustion, or the time taken for fuel to burn out after a live flame has passed. And, as Hobbs *et al* (1984) argue, measurement of temperature is also useful for the interpretation of the post-fire response of the life forms, especially where there is a critical lethal temperature, or where there is a temperature stimulus for germination.

For this study, therefore, the following characteristics of fire behaviour were measured, namely: maximum temperature and duration of maximum temperature at ground-level; the spatial pattern of temperature; the rate of fire spread; the pattern of fire spread; and flame height.

4.2.1.1 Maximum temperature and duration of maximum temperature at ground-level

The duration of temperature is the measurement of the length of time a given level of temperature is attained at a given point in a burn. It was measured, for the first time in Thailand, in all the experiments, by means of a heavy duty, non-contact, infra-red digital pyrometer, with a temperature range from 0°C to 1000°C. The instrument has peaking, memory and averaging facilities; its distance/target ratio is 40/1; and the speed of response is 3 readings/s. An emissivity of 0.9 was selected, as it was found to correlate well with a standard thermometer reading. This instrument is easier to use, and far more reliable, than more traditional thermocouples, which can be prone to large errors if not used with caution. Moreover, the latter must be connected to recording equipment that has to be installed and protected from the fire (Vines 1981, Hobbs *et al* 1984).

However, the full potential of the pyrometer was not exploited

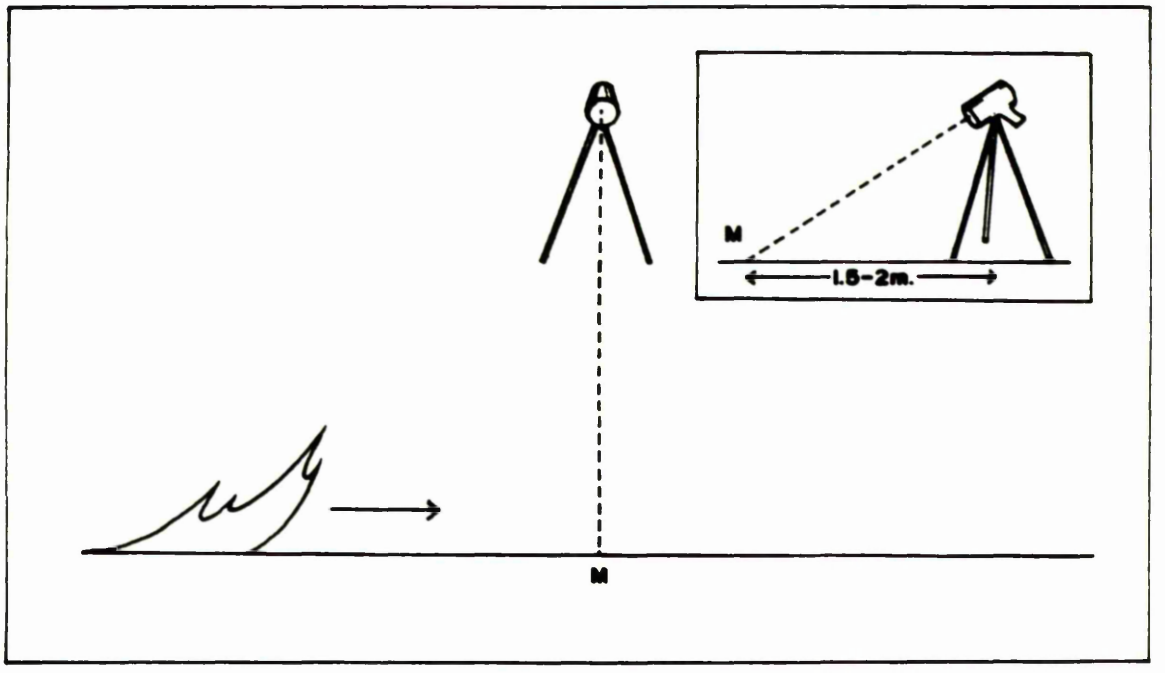


Figure 4.1. Diagram showing how duration of temperature is measured by an infra-red pyrometer. (M = measuring point).

in this thesis. In the field, the pyrometer reading had to be taken manually, and as the instrument response is too fast to follow by hand with accuracy, it was decided to record one reading at every 5 s. The point of measurement in all burns was always at ground-level, usually at 1.5 m from an ignition point (see Fig.4.1). Other levels were not measured, because, in an open forest burn, if a measurement is aimed at a higher point (e.g. a grass clump at 1 m above the ground), it cannot be ascertained whether or not the pyrometer is reading other focusing points further away, or smoke, which can easily come between the point being measured and the pyrometer. This is particularly important if it is aimed downwards, at an angle, so that it eventually focuses on another point at ground-level, beyond the intended measuring point.

Temperatures were recorded from the initial air temperature to the temperature peak, and as the temperature declined, stopping when the temperature dropped below 50°C. However, when there was any serious risk to either myself, or to my assistant, measurement was inevitably disrupted.

4.2.1.2 The spatial pattern of temperature

This was measured in the burns on the *Dipterocarpus* 1 stand only. The most popular method of measuring the spatial pattern of forest fire temperatures has been the use of heat-sensitive paints, or crayons, painted on to mica, aluminium, or asbestos, because these provide a cheap and extensive sampling system (e.g. Whittaker 1961, Sukwong 1977, Hobbs *et al* 1984). Such heat-sensitive paints undergo irreversible colour changes at known temperatures. The pyrometer used in this study was of the type originally developed by Hobbs *et al* (1984) in their study of Scottish heathland fires. This was later used by Stott (1986) in dry dipterocarp forest fires in Thailand.

The pyrometer is made up of 11 'Thermocolor' heat-sensitive paints, sandwiched between two 'spotted' mica sheets, each approximately 5 x 4 x 0.0004 cm. The paints give 15 colour changes that cover a temperature range in the field from 75°C to over 1000°C. They come in powder form and were manufactured by A.W.Faber-Castell of Stein bei Nurnberg, West Germany, while mica sheets were supplied, ready cut, by Mica and Micanite Supplies Ltd., London. 10 g of paint powder were mixed thoroughly with 7 g of methanol (CH_3OH), although paint No.10 did not mix well at all, and it easily flaked off when dried. Paint No.23 and No.16

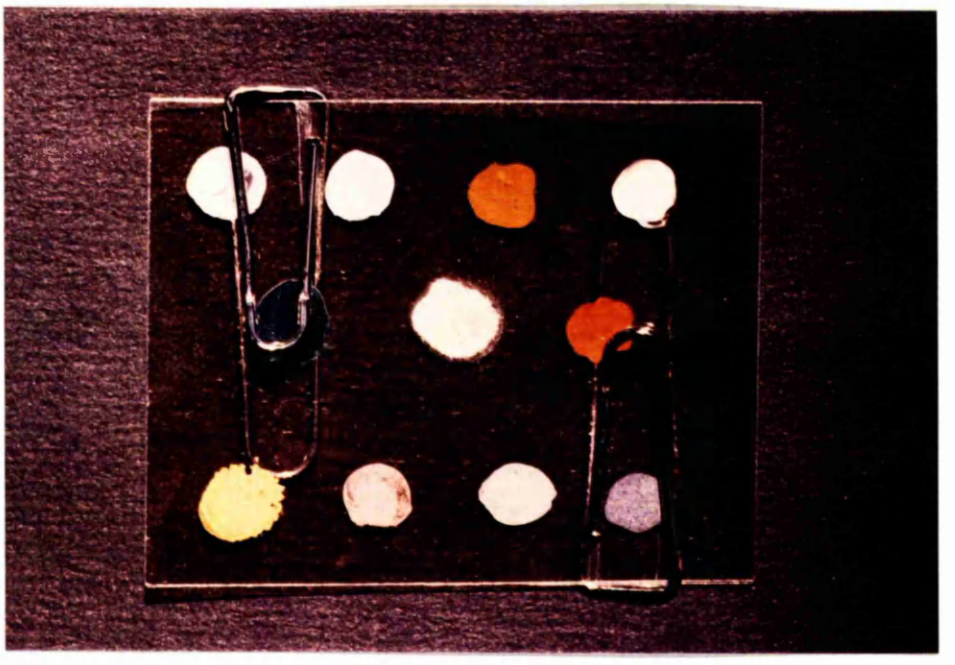


Figure 4.2. 'Thermocolor' pyrometer. (photo by R.Davies).

were rather thick and difficult to apply thinly and evenly, so as to give the best results (Stott 1986). For each colour, a dot of about 0.5 cm is painted on the mica sheet, using a split piece of bamboo with one end beaten to fine fibre and trimmed like a brush. This was used as an alternative to the normal small bristle-hair brush, because the latter is very expensive and difficult to find in Thailand. Seperate pieces of bamboo 'brush' were used for each paint, to avoid any contamination. Each colour was mixed and painted on, one at a time, for they dry quickly, within about 2 hours. Hobbs *et al* (1984) and Stott (1986) distributed the 11 paints over both sheets of a mica sandwich; they then attached them together with hard metal paper clips, the paints being protected inside. In the present case, all of the 11 colours were painted on one single sheet, then sandwiched and clipped to a blank piece of mica (Fig.4.2).

For interpretation, each batch of 'Thermocolor' pyrometers needs to be recalibrated (Hobbs *et al* 1984). Unlike the brief duration of maximum temperature in a forest fire, the manufacturer's calibration is for industrial use, and based on a 30 min exposure on a large metal body. The manufacturer has further shown that colour changes could occur at different temperatures if the exposure time is varied, with colour changes produced over a shorter duration only by temperatures higher than those obtaining over a longer exposure period. The variation, if it occurs, is greatest in the first minute, with up to 50-60°C difference, as Hobbs *et al* (1984) demonstrated in their calibrations over 15 s and 30 s exposure time.

In this study, two sets of pyrometers were calibrated. The first was done over 30 s exposure time in early 1988, before field measurements of duration of temperature were analysed. A muffle furnace at Kasetsart University in Bangkok was used. Later, however, when the mean duration of maximum temperature for a head fire burn on ground cover and leaf litter was known to be <10 s, it was decided to calibrate another set of pyrometers over 10 s exposure time in 1990. This was done in a muffle furnace at the Department of Geography, University College London.

Calibration was done in 25°C steps, from 50°C until the mica surface disintegrated to the point where reading the colour change was no longer possible. This occurred at 800°C and 850°C for the exposure times of 10 s and 30 s respectively. In each case, the calibration was repeated three times. The results are given in table 4.2, with additional notes on other possibilities that might occur. Colour changes, as Stott (1986) found previously, are not always sudden and clear. On the whole, their effectiveness is also comparable to Stott's calibration at 20 s, although

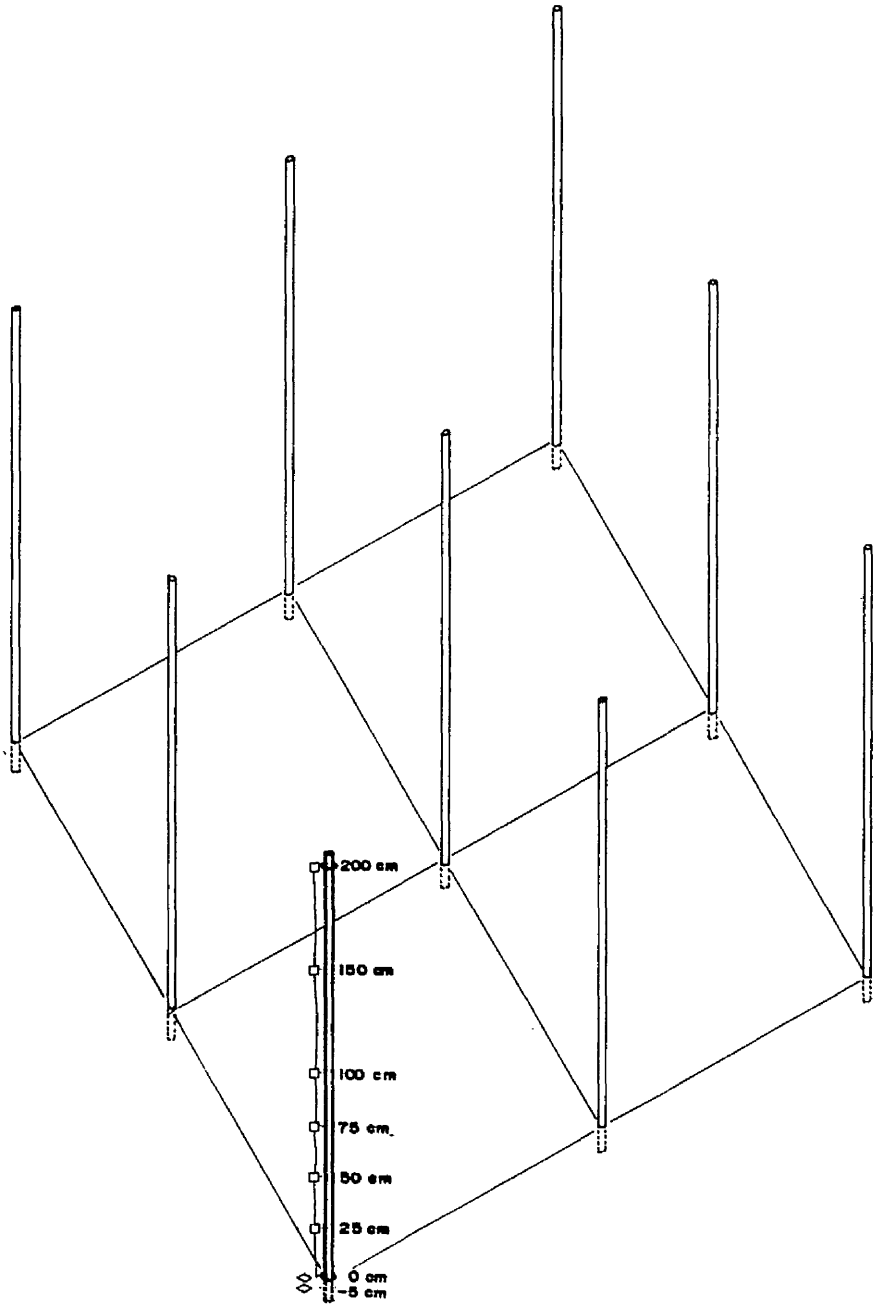


Figure 4.3. Diagram showing how the spatial pattern of temperature was measured. A series of 'thermocolor' pyrometers were attached to a free piece of wire, hanging down an aluminium pole.

Table 4.2: Temperature calibrations of the 'thermocolor' pyrometers used in the experiments.

PAINT NO.	COLOUR CHANGE	TEMPERATURE (°C)				
		MANUFACTURER'S 30 min duration	30 s DURATION		10 s DURATION	
			Common changes	Possible changes	Common changes	Possible changes
41: light green	light blue	65	75		125	
	yellow	145	150			175
	black	220	250	275	275	250
	black-brown	340	350		400	
23: blue	yellow-brown	240	250		275	250
	black	340	375		400	350
	edge or half		350			350 375
7: yellow	red-brown	290	300		325	300
8: white	brown	340	375		375	350
	slight tint		250		275	150
	edge or half			100		325
9: * green	white	440			450	
	cracked			450		
	grey or blackened		500		525	

* Paint No.9 never changed colour in the field

Table 4.2, continued.

PAINT NO.	COLOUR CHANGE	TEMPERATURE (°C)				
		MANUFACTURER'S 30 min duration	30 s DURATION		10 s DURATION	
			Common changes	Possible changes	Common changes	Possible changes
10: peach	light grey	520	450	425	500	
	growing edge		275-350		300	
	growing light tint				400-475	
11: orange	yellow	560	400		550	525
	edge		375		450	400
	half					525
13: yellow	olive	715	750		750	725
	edge		375			
	half			425		725
14: grey	dark brown	900	Neither calibration was done beyond 850°C *			
15: green	brown	1000				
16: light blue	blue-black	1100				

* 30 s duration. By 850°C, the mica sheets had cracked to the extent where their surface became totally opaque, and further reading was no longer possible.

10 s duration. Mica sheets became opaque by 800°C.

the changes here can sometimes be more gradual, with one or two paints not working so well, as will be described presently. This probably reflects the paints shelf-life and their exposure to humidity, having come from the same bottles as Stott's (1986) study that were left in Thailand since 1985[9].

Colour changes in the calibration over 10 s exposure time tended to occur at 25-50° C higher than when they were exposed over 30 s, which was expected from Hobbs *et al*'s (1984) experiment. 'Thermocolor' pyrometers, however, do not store very well in the humid tropics, as was evident in the calibration over 10 s, which was done two and a half years after they were made. Although most colour changes still occurred and could be recognized easily, the changed colour was often noticeably paler. The second colour change (yellow) on paint No.41 did not always occur, and paint No.10 only changed partly. In reverse, paint No.9 changed colour effectively in this case, although it had never done so before, either in the field or in a furnace, as Hobbs *et al* (1984), Stott (1986) and myself had previously experienced. Otherwise, most colour changes in both calibrations tended to be good, and many were sudden, with up to only 25-50° C margin of error. The first hint of any change in many colours, however, actually appeared some 150-400°C before a complete change took place (Table 4.2). Generally, changes at higher temperatures were less effective. Change on paint No.10 was recognizable, but it was gradual, and the paint often disintegrated to powder. Change on paint No.13 was sometimes difficult to recognize. Paint No.14 never changed in both calibrations. Therefore, if a change in this paint occurred in the field, it was interpreted as being exposed to temperatures of >850°C. The interpretation of a head fire burn is based on calibrations over 10 s duration, and a back fire burn over 30 s duration.

Before each burn, pyrometers were individually coded by scratching the outer surface of the mica sandwich with a sharp metal point. The code stated the burn, the number of the sampling point, and the height or depth where the pyrometer was to be placed (e.g. burn A, first point at 50 cm above the ground would be 'A1+50'). The coded pyrometers were then attached to a metal wire, which ran freely down a 2.25 m aluminium post that served as a sampling point, with measuring points at 5 cm under the ground, at ground-level, and above the ground at 25 cm, 50 cm, 75 cm, 100 cm, 150 cm, to 200 cm high (Fig.4.3). Nine sampling posts

[9] The paints are now unfortunately no longer available, because of legal restrictions placed on their production by the German government.

were used in each burn. Their positions were geometrically placed within a grid system, initially laid out for the study of the ground vegetation (see Section 4.2.2). Within 1 m^2 of a sampling grid centre, however, the sampling point was sometimes deliberately chosen for comparable fuel distributions in different burns, e.g. on grass clumps, on leaf litter, etc.

4.2.1.3 The speed of fire spread

The mean rate of fire spread (cm s^{-1}) is calculated by the following equation:

$$\frac{\text{mean distance of spread (cm)}}{\text{total burning time (s)}}$$

In turn, the mean distance of fire spread is calculated by the equation below:

$$\frac{\text{total sum of distance spread from all directions measured from the ignition point}}{\text{number of measured directions}}$$

4.2.1.4 The pattern of fire spread

In the *Dipterocarpus* 1 burns, the method of recording fire spread developed by Mather (1978a) was used. A series of numbered metal discs were dropped along the fireline at 2 minute intervals, starting from the first 4 minutes after ignition. For example, discs numbered '4' were dropped at the fourth minute, and those numbered '6' at the sixth minute, and so on. When a burn was finished, compass bearings and the distances of these discs from the ignition point were recorded.

For this research, the metal discs were made by cutting an iron sheet into small squares of about 4"x 4". Numbers were stamped on, as well as painted on, to ensure easy recognition after the burn.

4.2.1.5 Flame height and frontal fireline intensity (I)

Frontal fireline intensity (I) is commonly used to describe the energy output rate per unit length of fire front, and it is usually expressed in terms of kilowatts per metre (kW m^{-1}). There are a number of ways determining the value. One of the simplest means is to derive it from the flame height (L) measured in metres, using the following formula,

after Byram (1959):

$$I = 259.833(L)^{2.174}$$

The problem with this method is that an estimation of flame height is very quick and rough by nature, while the calculation is so fine that a small difference in flame height would lead to a large difference in fireline intensity. Moreover, flame height constantly changes in a burn, as do other characteristics of fire behaviour. To counter these limitations, mean and maximum flame heights were estimated in the same sequence as with fire spread. Two metre high aluminium poles, with marks at every half metre, served as measuring stakes against which flame height was estimated.

4.2.2 Measurement of fuel and vegetation

In dry dipterocarp forest, fuel may be divided into five main categories, namely: grasses; non-grass ground cover, which includes all evergreen or deciduous herbs, forbs and seedlings; fallen leaves, flowers, and fruits (litter); dead woody fuels of various sizes; and fine broken matter (fines). The fine matter, and small twigs, was found to be relatively insignificant in most dry dipterocarp forest subjected to annual burning. Fallen flowers and fruits were also insignificant during the sampling year. Thus, three main fuel categories were sampled and observed regularly, namely: grasses; non-grass ground cover; and leaf litter. The larger woody fuels were mapped when they occurred. This included branches and logs on the forest floor, and dead standing trees and shrubs.

The internal properties, and the external characteristics of the fuel, as well as its ignitability and fire sustainability, were recorded on a monthly basis, from October 1987 to November 1988, and at the time of an experimental burn. Fuel internal properties include factors such as dry weight (biomass), internal moisture content, calorific value, fibre structure, and nutrient composition of the fuel. However, in this research, only moisture content and biomass were sampled.

External characteristics include factors such as external moisture content, like dew; the arrangement and the spatial distribution of the fuel; the composition and the ratio of fuel types; height of fuel; leaf litter depth; ground cover density; and cover percentage of each fuel type. Most of these were measured, or estimated. However, the external moisture content of the fuel was not recorded, for most ground cover burns were ignited at a more or less constant, dewless time of the day, between 13.00 to 14.00 in the afternoon.

4.2.2.1 Biomass and moisture content

In the *Dipterocarpus* 1 stand, three small plots were set aside for the monthly sampling of ground cover biomass and moisture content. One square metre was taken from each plot, and grasses and non-grass species from each sample were separated. These were weighed immediately after collection (green weight), and re-weighed after being oven-dried at 80°C for 48 hours (dry weight). This dry weight, in grammes (g), was taken as the biomass, while the percentage of internal moisture content was calculated using the equation below:

$$\frac{[\text{green weight} - \text{dry weight}] \times 100}{\text{green weight}}$$

Litter biomass was sampled by collecting litter fall in 5 x 1 m^2 collecting baskets, which were placed in a protected 10 m x 10 m plot in the *Dipterocarpus* 1 stand. Litter biomass and internal moisture content was determined in the same way as for ground cover.

For experimental burns in other forest stands, only moisture content was determined. Thus, only two clumps of grass were sampled, taken from the base at ground-level. If leaf litter was significant, samples of 10-15 leaves were gathered at random, from the top, middle, and bottom layers.

4.2.2.2 Ignitability and sustainability

Ignitability and sustainability of fuel were tested monthly on samples from the *Dipterocarpus* 1 stand. In this thesis, ignitability is defined as 'the capacity for vegetation to be ignited', and sustainability as 'the capacity for vegetation to sustain fire', which Philips (1974:443) termed 'flammability' and 'potential combustibility' respectively. These were tested in a closed, windless room, by holding the full length of a leaf (i.e. grass blade, leaf of a non-grass species, or leaf litter) at the horizontal, with one end in contact with a candle flame. The speed of ignition and the distance the flame was able to travel were the criteria on which ignitability and sustainability were judged, using the scales below:

Ignitability	Sustainability
0. will not ignite after 30 s	
1. ignites in 20-29 s	1. burns at flame point only
2. ignites in 10-19 s	2. burns less than 1/4, or < 5 cm
3. ignites in 5-9 s	3. burns 1/4 to less than 1/2, or 5-9 cm
4. ignites in a few seconds, but less the 5 s	4. burns 1/2 to less than 3/4, or 10-14 cm
5. ignites instantly	5. burns 3/4 or over, or ≥ 15 cm

Ten specimens were tested for each fuel category, taken from samples collected in the same way as for the biomass. Leaf litter samples were gathered from a 1 m^2 collecting basket placed in the fire break, which was not used for biomass sampling.

This method is a very simple test of the ignitability and sustainability based on internal properties of the fuel only. It ignores, of course, the external characteristics of the fuel.

4.2.2.3 Ground cover height and leaf litter depth

For each plot in the *Dipterocarpus* 1 stand, 10 specimens of each dominant seedling species were individually tagged so that their growth could be monitored monthly, where the tip of the top shoot was taken as the measured height. Height of grasses and other non-grass species were also recorded monthly. In the case of the grasses, the stems were never stretched when measurement was being taken, but the grass arrangement was noted, whether it was fallen, or in a standing position. In this way, the measured height of grasses and other ground vegetation are the true 'height', or distance, from the ground, which is an important variable in respect of fire. At the same time, during the rainy season, this measured 'height' may still largely represent grass growth, because the grasses stand erect during this period. For each grass and non-grass--non-seedling species, 10 random samples were measured with additional measurements of the tallest and the shortest specimens in each plot. Similarly, leaf litter depth (measured by the number of overlapping leaves) was recorded monthly from 10 random points and two extreme points per each plot.

In other experimental plots, the ground cover height and leaf litter depth were measured prior to fire ignition.

4.2.2.4 Fuel arrangement

The term 'fuel arrangement' as used in this work only implies the direction in which the body of the fuel is placed, whether horizontally or vertically, for instance. It does not include the sociability of

each fuel type, which will be discussed later. As the positions of leaf litter and most non-grass ground cover were always consistent throughout the year, data on fuel arrangement only concerned grasses, providing an estimate of the ratio of fallen grass stems in proportion to the upright ones. Special note was made where grass stems were displayed at an angle, as in the case of a burn on *Chrysopogon orientalis* A.Camus.

The arrangement of important grass species was noted every month in the *Dipterocarpus* 1 stand, and prior to burns at the other sites.

4.2.2.5 Cover percentage and density

Cover area of the ground vegetation, leaf litter, or canopy were all estimated. In the *Dipterocarpus* 1 stand, this was done at the end of every month. However, as the cover area of the ground cover does not always represent density, estimation of density was taken before every ground cover burn, based on the scales below:

Cover value	Basal area
1. 50% or less	1. less than 10%
2. 51-70%	2. 10-19%
3. 71-80%	3. 20-29%
4. 81-90%	4. 30-39%
5. 91-100%	5. 40% or more

4.2.2.6 Phenology

The phenology of some important ground cover species and canopy trees was observed monthly in the *Dipterocarpus* 1 stand. For the ground cover, the timing of flowering, fruiting, plant withering or leaf shedding, leaf flushing, and the appearance of new plants were noted. In the case of canopy trees, in addition to leaf shedding and flushing, flowering and fruiting, the time of fruit fall was also observed. This was further cross-checked with litter fall in the collecting baskets.

4.2.2.7 Ground cover species composition

Species diversity and species distribution patterns, in terms of their cover area and sociability, were counted and estimated three times in the *Dipterocarpus* 1 stand. The first was at the end of October 1987, which was at the start of the field work; the second time was at the end of January 1988, in the middle of the dry season; and the last was at the end of November 1988, or the end of the observed period. It was unfortunate that the last species count, and their cover estimates, could not have been done in October 1988, the same month as the previous year,

but an unusually heavy flood had made the wildlife sanctuary inaccessible during September and October 1988.

The estimation of ground cover distribution patterns was based on the scales below:

Cover value	Sociability
0. one single plant	0. one single plant
1. less than 5%	1. single plants widely distributed
2. 5-24%	2. scattered small clumps
3. 25-49%	3. many moderate clumps
4. 50-74%	4. few big clumps
5. over 75%	5. one big 'island'

Each 10 m x 10 m plot in the *Dipterocarpus* 1 stand was divided into 16 grid squares, where each grid square was 2.5 m x 2.5 m, or a quarter of the length of 10 m. This helped considerably in estimating ground cover sociability and species cover percentages. Plant species were identified locally with the help of *Khun* Muuk, a local botanist from Khao Nang Rum Research Station (see site description, Section 4.4). Specimen taxa were also collected. Part of these specimens were kindly identified by Dr. Tem Smitinand at the Royal Forest Department Herbarium in Bangkok, the other part being identified with samples collected by Mr. Somsak Wanussakul, who was working on his M.Sc thesis in another *Dipterocarpus* association nearby.

Although one year's study is far too short a period to observe any significant changes in species diversity and dominance, the study may at least give some indications of the potential vegetation composition in response to different fire timings.

4.2.3 Measurement of the general environmental conditions

Because the thesis focuses primarily on the relationship between fuel characteristics and fire behaviour over the dry season, interplot variations in general environmental conditions were kept to a minimum. Environmental factors fall into three main categories, namely: soil, topography, and atmospheric conditions.

4.2.3.1 Soil

Soil moisture content was determined monthly in the *Dipterocarpus* 1 stand. For each month, three samples were taken from the three sampling plots set at different corners in the stand. Each sample was divided into two layers: a) from 0-5 cm deep, and b) from 5-15 cm deep. The moisture content was tested in the same way as for the internal

moisture content of the fuel.

4.2.3.2 Topography

For this research, slope was kept constant, at $\leq 5°$, which means that aspect was also fairly insignificant as a variable. Because slope is a very important variable which can dramatically influence fire behaviour, soil erosion, and, therefore, vegetation recovery, it was decided to control slope for these experiments.

Most test burns were carried out around 460 m.a.s.l., with a few burns at lower altitudes. Altitude was determined with a pocket altimeter, and it was checked by reference to the contours on a 1:50,000 map (Sheets 4839I/Khao Manora, 4840II/Doi Pasang; Series L7017; Edition 1-RTSD; Royal Thai Survey Department 1983).

4.2.3.3 Atmospheric variables

Wind speed ($m\ s^{-1}$) was measured with an anemometer, although for safety reasons, burns were carried out only under low wind conditions, so that the anemometer hardly ever responded. The ignition time for most ground cover burns was kept more or less constant, between 13.00 to 14.00 in the afternoon, when the air temperature is at its highest and the humidity is lowest all through the dry season. The amount of sunlight penetrating through the forest canopy was estimated, and note was taken of whether the sky was sunny or cloudy.

4.3 Choice of site

The study site at Khao Nang Rum Research Station in Huai Kha Kheang Wildlife Sanctuary, Uthai-thani province, West Thailand, was chosen for several reasons. First, it has extensive stands of dry dipterocarp forests, well protected from major recent disturbances, at least in the last 30 years (Galong Srima, pers.comm.). This protection is important because it above all excludes logging and intensive firewood collecting, both of which could have confused any evaluation of fire impact on the vegetation.

Furthermore, under its official status as a Wildlife Sanctuary, the site is not freely open to tourists or other visitors, thus minimizing extra human interference in the creation of fire, such as unwanted 'accidental' burns on permanent experimental plots during the research year. Yet, Huai Kha Khaeng Sanctuary still has long-standing human interactions, and there are extensive human-induced fires occurring every year. The eastern border of the sanctuary is dotted from north to

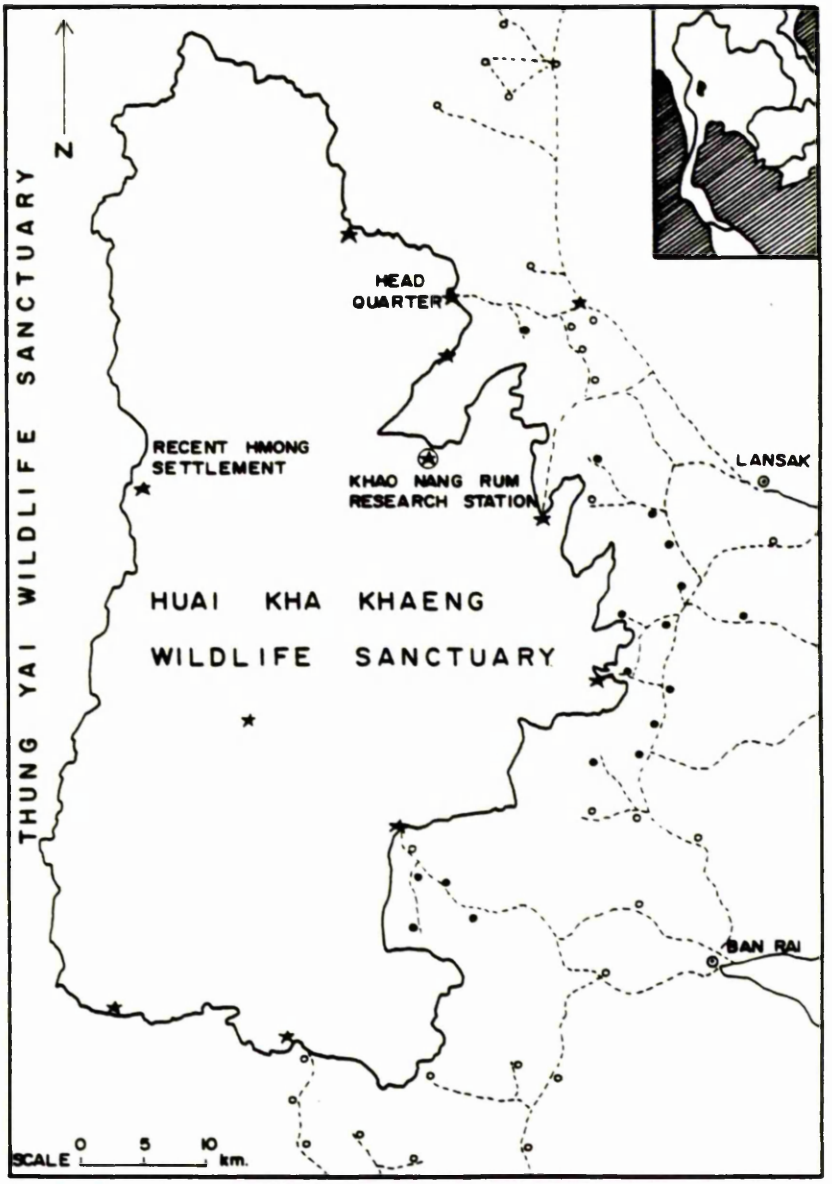


Figure 4.4. Map of Huai Kha Khaeng Wildlife Sanctuary. (Source: Faculty of Forestry, Kasetsart University, Bangkok, 1988).

south with Thai and Karen villages, and within the sanctuary itself, there are more Karen, and recently evacuated Hmong villages, the nearest being just over 30 km westward from Khao Nang Rum Research Station. The sanctuary is quite heavily poached, and hunters and forest product gatherers frequent the area. There is also an ancient caravan route by Khao Nang Rum Station. Forest monks, army rangers, and probably drug traffickers, occasionally pass through. Thus the dry dipterocarp forests here, although protected, are not 'untouched' by humans.

4.4 Site description

Situated mainly in the west of Uthai-thani province, the area of Huai Kha Khaeng Wildlife Sanctuary extends partly into Tak province, which lies in the west. The sanctuary boundary meets Nakorn-sawan province on the north, Suphanburi on the southeast, and Kanjanaburi on the south. It abuts on the east to the famous Thung Yai Wildlife Sanctuary, and together they form part of Thailand's 'Great Western Forests', which adjoin Burma Luwaing, Heinze and Kaleinaung forest reserves across the Thai border. This makes the area the single largest legally protected forested land in Southeast Asia. Huai Kha Khaeng Wildlife Sanctuary itself occupies an area of 2575 km^2, being situated within 15°00'-15°50'N, 99° 00'-99° 39'E (Nakhasathien *et al* 1987). The sanctuary is named after its major water course, the Huai Kha Khaeng, which transects the sanctuary from north to south, joining the Mae Klong, that flows from the Thung Yai Sanctuary, to form the Kwae Yai river in Kanjanaburi province, just below the southern boundary of both sanctuaries.

The terrain of the Huai Kha Khaeng Sanctuary is hilly, partly undulating, but mainly steep land from around 300->1000 m.a.s.l., with shallow Red-Yellow Podzolic soils derived from acid to intermediate rocks - a combination of granite, granodiorite, diorite and associated intrusive rocks and gneiss, Precambrian to Cretaceous in age (Land Development Department 1967, Department of Mineral Resources 1983). Acidic Red-Yellow Podzolic soils on residuum and colluvium are also present, confined to some river valleys, such as Huai Kha Khaeng and Tub Salao, the latter running near the Sanctuary's eastern boundary near the Head Quarters. Virtually all the underlying rocks possess little or no ground water. These include some complexly folded Cambrian to Devonian metamorphic rocks, predominantly slates, phyllites, quarzites and schists, found on the western strip and southern tips of the sanctuary. Limestones, of the Permian Ratburi Group and Ordovician Thung Song Group, occur in only small areas, in contrast to Thung Yai Sanctuary, where they are almost

predominant, often bearing Red-Brown Earths.

Thung Yai Sanctuary, with overall higher lands directly facing the southwest monsoon, generally receives a higher rainfall of between 1400-2500 mm per annum, while 1000-2000 mm of rain falls on most parts of Huai Kha Khaeng, with an average relative humidity of 65-70%. Coupled with the predominantly dry soils, Huai Kha Khaeng Sanctuary is accordingly covered with more dry dipterocarp forest than Thung Yai Sanctuary. The dry dipetrocarp forest often occurs in a mosaic with monsoon forest and areas of bamboo, with dry evergreen forest occurring on moister locations, and hill evergreen forest at higher altitudes, generally above 1000 m.a.s.l. (Smitinand 1962).

The actual study site, Khao Nang Rum Research Station itself, usually receives an annual rainfall of 1000-1500 mm, occasionally up to 2000 mm. It is situated some 16 km from the Head Quarters at the Sanctuary's eastern boundary, northeast of the research station, at an altitude around 460 m.a.s.l. Small undulating hills comprise the immediate vicinity of the research station (400-600 m.a.s.l.), but the area is almost enclosed by ranges of bigger mountains. On its east, only about 1 km from the station, is Khao Khiew, which forms part of Khao Yai range, one of the highest peaks in the sanctuary (1554 m.a.s.l.). The south and southeast face Khao Nam Yen, and towards the north lie the ranges of Khao Daeng. Crossing over Khao Chong Lom on the west is the Huai Kha Khaeng river, from where the land climbs higher westward, forming parts of the Great Tanaosri Range in Thung Yai Sanctuary. Two main streams embrace Khao Nang Rum Research Station: the Huai Chang Tai on the west and the Klong Kor on the south, which join 30 km up the Huai Ai Yoa, one of Huai Kha Khaeng's main tributaries.

A mosaic of dry dipterocarp forest and monsoon forest on shallow Red-Yellow Podzolic soils is the predominant pattern around Khao Nang Rum Research Station, with semi-evergreen forest restricted largely to water courses. Indeed, for the whole of Huai Kha Khaeng Sanctuary, monsoon forest comprises around 40% and dry dipterocarp forest around 45% of the entire area, the rest being dry evergreen, moist evergreen, and hill evergreen forest (Nakhasathien *et al* 1987). Many association types of dry dipterocarp forest are found here, ranging from both the xeric and mesic *Shorea* associations to some very fine three-storeyed *Dipterocarpus* associations, which are dominated by *Dipterocarpus tuberculatus* or *D.obtusifolius*, growing up to 25-30 m tall. The relatively moist mixed dry dipterocarp forest is also present.

SITES OF EXPERIMENTAL PLOTS

1. *Dipterocarpus* 1, 460 m. a.s.l.
   Dipterocarpus 2, 460 m. a.s.l.
2. *Shorea* 1, 460 m. a.s.l.
3. *Shorea* 2, 270 m. a.s.l.
4. *Shorea* 3, 210 m. a.s.l.
5. *Shorea* 4, 210 m. a.s.l.
6. *Shorea* 5, 230 m. a.s.l.

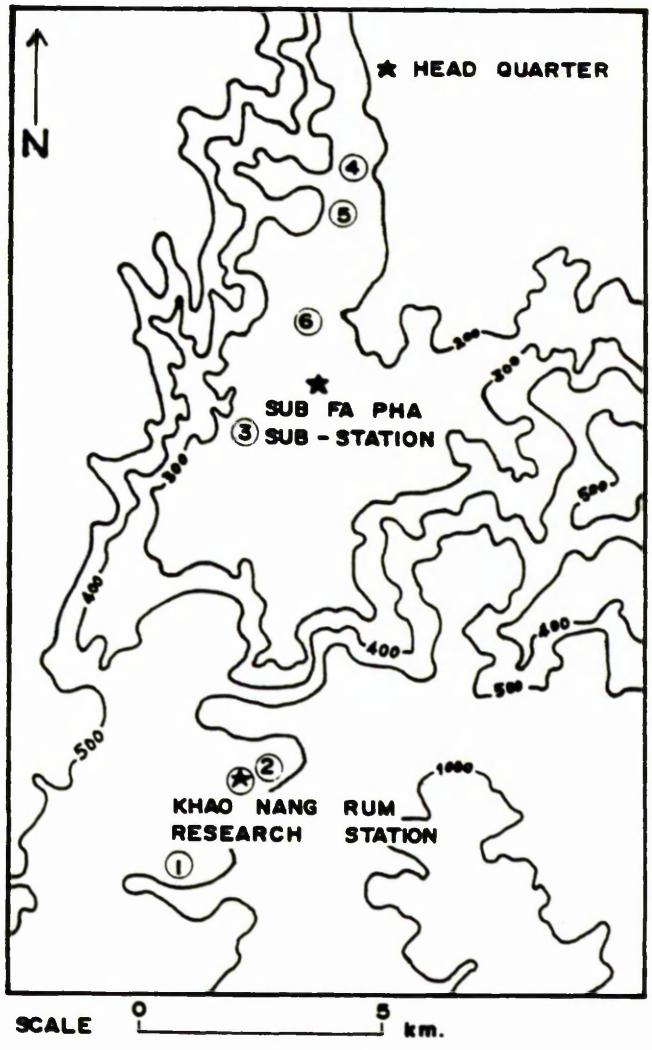


Figure 4.5. Map of Khao Nang Rum Research Station, showing the locations of the experimental burns.

Although the climatic and edaphic factors are both favourable for dry dipterocarp forest, much of the formation in these areas are probably derived from the adjacent dry evergreen and monsoon forests, with remnants of moist forest tree and lichen species persisting (Wolseley & Aguirra-Hudson, pers.comm.), even in the well-established open *Shorea* association stand. Some dry dipterocarp forest, however, is quite ancient, with the earliest human interactions known to have occurred well back in prehistoric time, which was probably preagrarian (Kanjanavanit 1986). The 'Great Western Forests' of Thailand are rich in both prehistoric and historic archaeological sites, and Khao Nang Rum is no exception. In an open *Shorea* stand only a few kilometers northeast of the station, several

secondary jar burials have been found within stone circles, locally known as *Wong Tee Gai*, meaning 'cock fight ring'. One was dated around 650 b.p. (Sangvichien & Subhavan 1981).

Today, humans continue to interact with the dry dipterocarp forests of Khao Nang Rum. These formations are, therefore, clear examples of dry dipterocarp forests that have been derived fairly recently, under the stress of the axe and fire, but within the general control of climatic and edaphic factors. The combination of these variables continues to maintain them.

4.5 Plot description

Other than the permanent study plots in the *Dipterocarpus* 1 stand, where regular observations on fuel and vegetation development were noted throughout the year, the experimental plots included many small areas in different stands of dry dipterocarp forest, of both the *Dipterocarpus* and *Shorea* associations (see Section 4.1). Figure 4.5 maps all the study plots, and the general characteristics of the sites are now described below.

4.5.1 *Dipterocarpus* association 1: the permanent plots

This stand of the *Dipterocarpus* association is situated at around 15°28'N, 99°17'E, 2 km southwest of Khao Nang Rum Research Station, and at about 460 m.a.s.l. (Fig.4.8). It is a two-storeyed formation with around 60% canopy cover, with *Shorea obtusa* and *Dipterocarpus tuberculatus* as the codominant top storey trees. Other trees include species familiar in dry dipterocarp forest, such as *Terminalia alata* Heyne., *Shorea siamensis*, *Gardenia sootepensis* Hutch., *Dalbergia* spp, and *Buchanania latifolia* Roxb., as well as those characteristics of monsoon forest, from which this formation was derived, such as *Spondias pinnata*, and a *Mangifera* sp. Not uncommon are also a few members of the Fagaceae, such as *Quercus brandisiana* Kurz and *Lithocarpus polystachys* Rend. Many of these trees, however, are small specimens, which form the lower storey, along with *Dillenia obovata* (Bl.) Hoogl. and many shrub-trees, including *Diospyros castanea* Fletch., *Aporusa villosa* Baill., *Anneslea fragrans* Wall., and in particular, *Randia parvula* Ridl.

Ground vegetation covers around 80% of the forest floor, and comprises 30-40% grasses, with *Apluda mutica*, *Heteropogon triticeus* (R.Br.) Stapf.ex Craib., and *Sorghum nitidum* Pers. as the dominant species. Other important grasses are *Imperata cylindrica* and *Coelorachis mollicoma* (Hance.) Bor. The rest of the ground cover consists partly of

herbs, including many geophytes in the Zingiberaceae, like *Globba leucantha* Miq., *G.obscura* K.Lar., *Zingiber zerumbet* Smith, and *Curcuma parviflora* Wall., as well as a few ground orchids, like *Habenaria linguella* Lindl. Leguminous herbs of the family Papilionaceae are also common, e.g. *Desmodium* spp and *Crotolaria* spp, as are members of the Asteraceae (the Compositae), like *Eupatorium odoratum* L. and *Elephantopus scaber*.

Although there is no distinct shrub layer in this stand, small low shrubs are significant, including *Pluchea polygonata* (D.C.) Gagnep., *Leea indica* Merr., and *Grewia* spp, and in particular an unidentified *Flemingia* sp. and *Erythroxylum cambodianum* Pierre, which bears sweet edible red fruits. Other common edible fruiting low shrubs are *Ardisia crenata* Roxb. and *Polyalthia debilis* Finet.ex Gagnep. Having a large fleshy fruit of about one inch long, the latter is one of the common barking deer's (*Muntjacus muntjak*) favourite foods. Climbers are abundant, although only one, *Spatholobus parviflorus*, has grown into a sizeable specimen (dbh = 21 cm), winding up a trunk of *Dipterocarpus tuberculatus*.

Canopy tree seedlings form the remaining ground cover. Dominant species are *Dillenia obovata*, *Shorea obtusa*, *Dipterocarpus tuberculatus*, and those without mature specimens growing in the near vicinity, including *Vitex limonifolia* Wall., *Cratoxylum pruniflorum* Kurz, and a *Glochidion* sp.

This formation is a typical '*Dipterocarpus tuberculatus* - *Shorea obtusa* community' as described by Bunyavejchewin (1983), reflecting a comparatively moist association of the dry dipterocarp forest. Tree height of the top canopy ranges from 20 to 30 m, while the lower storey ranges from 10-17 m, with a few odd 5 m tall saplings growing sporadically. In October, at the end of the rainy season, the non-grass ground cover has a mean height of 40 cm and the grasses are around 1 m tall. The forest stand grows on an almost flat piece of sandy loam, with a very gentle 5° slope. The flat area is around 40 m x 60 m. An animal track, which links up two salt licks, cuts through its centre.

The site was chosen for the large area of flat land, which was big enough to accommodate all the plots and fire breaks needed. This is an important requirement because the permanent plots must be comparable ecologically, particularly when assessing their recovery after burns at different times in the dry season. Therefore, factors such as slope, aspect, amount of sunlight and rainfall received, as well as soils and parental rock, should be kept constant. In contrast, a single piece of flat land of this size is not often characteristic of the *Shorea* association,

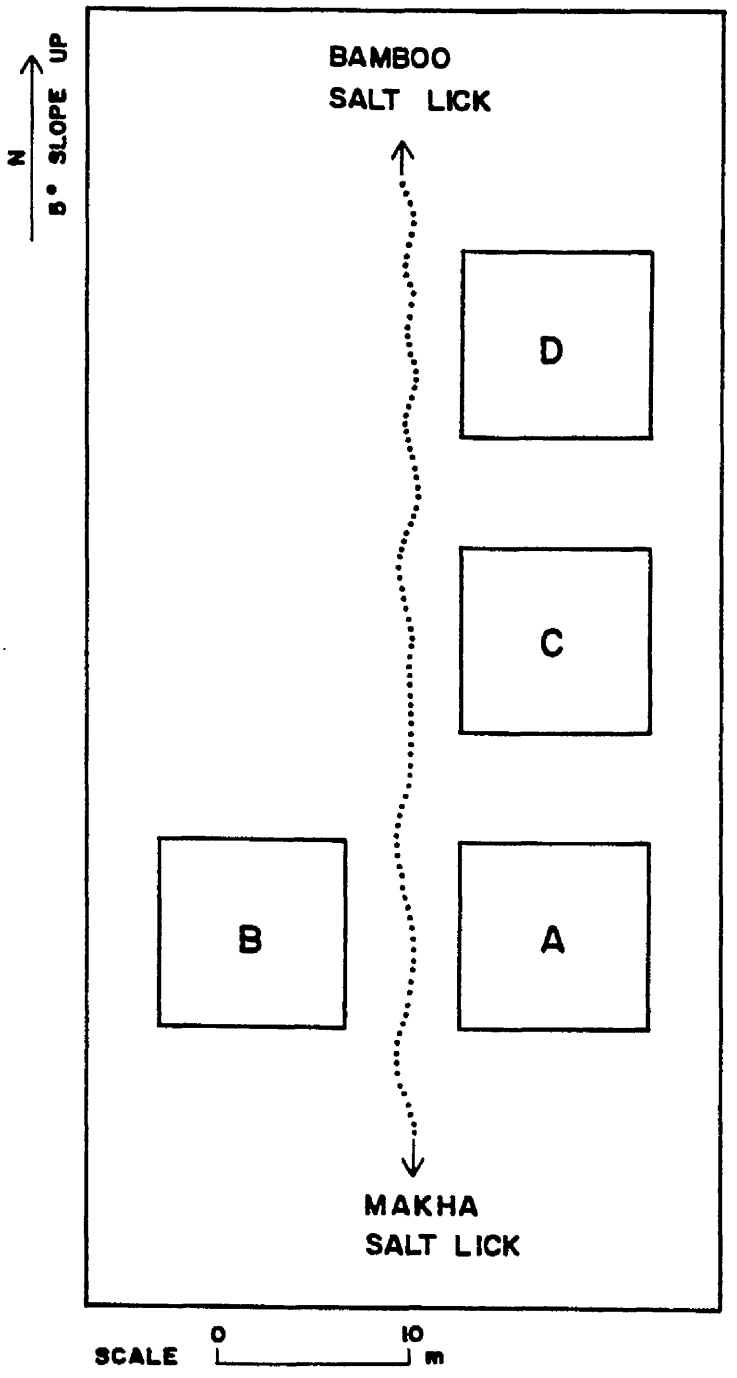
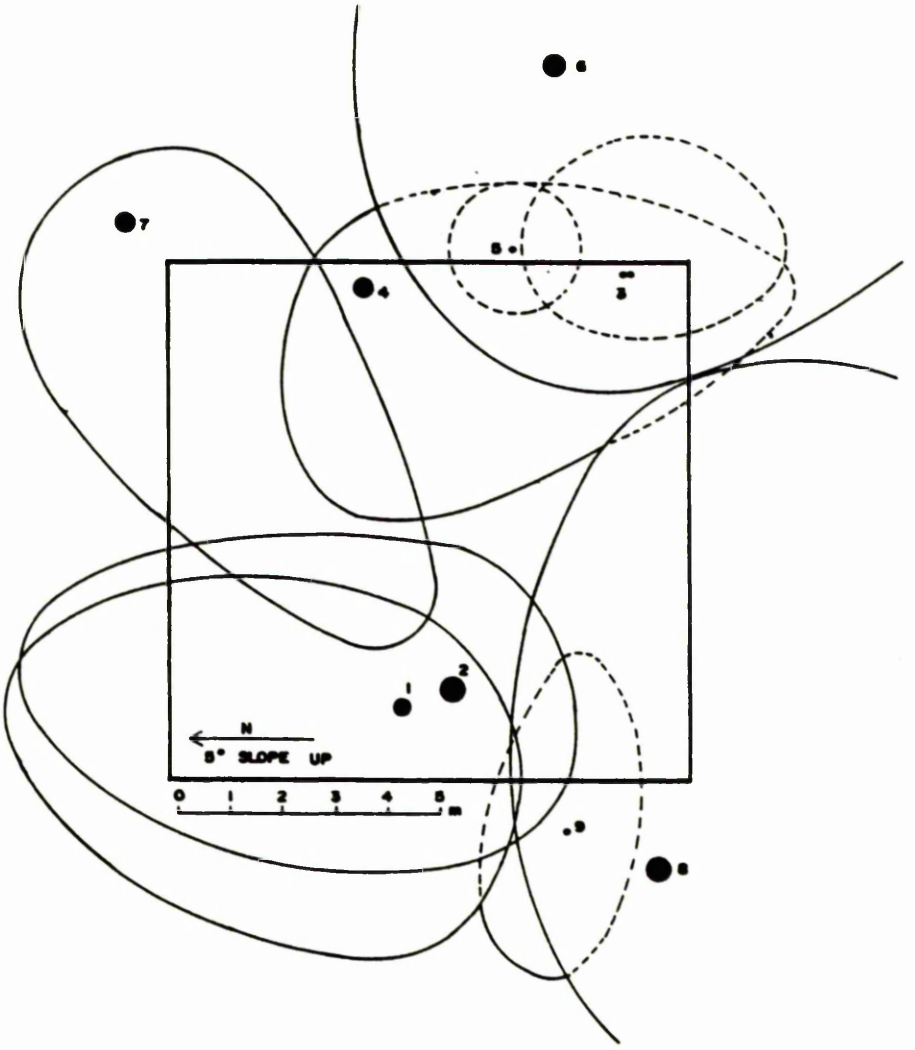
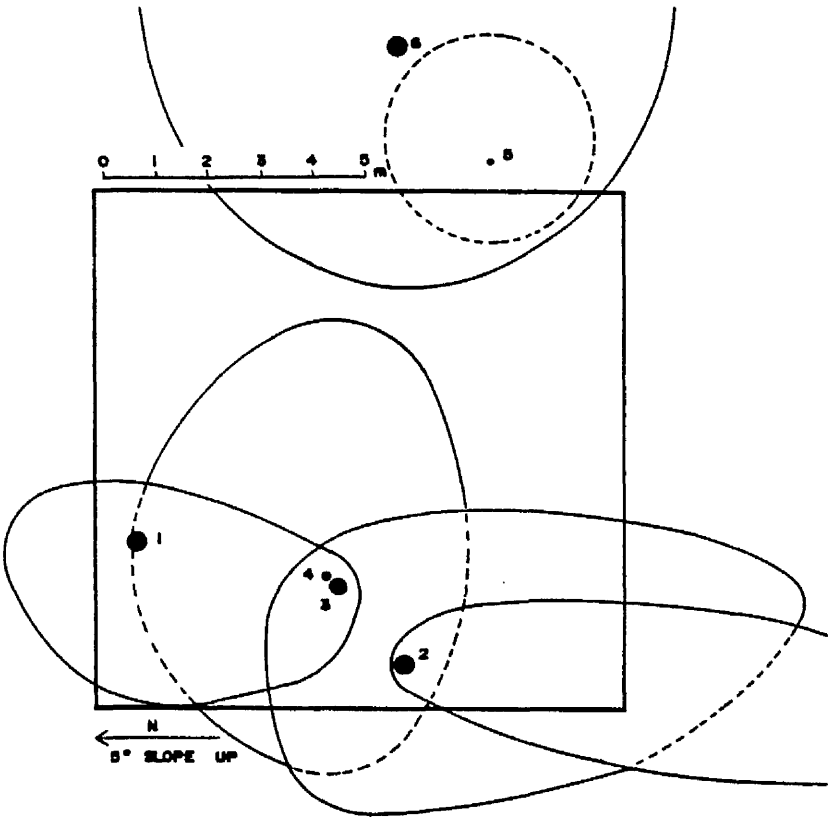


Figure 4.6. Plan of the layout of experimental plots in the *Dipterocarpus* 1 stand.



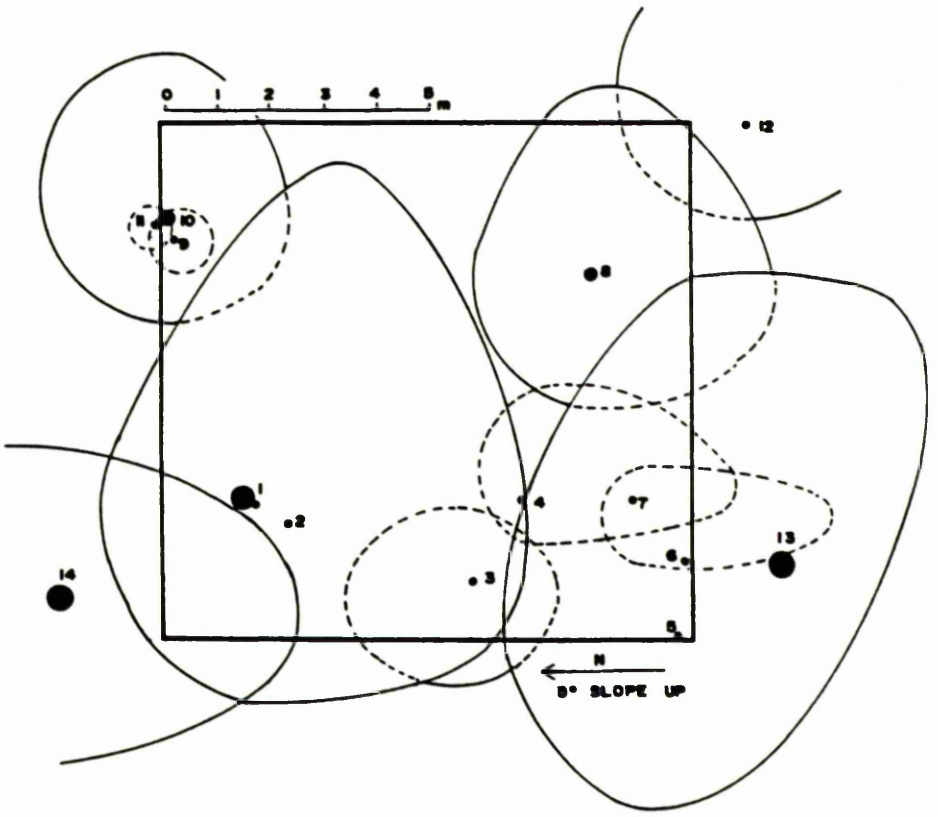
1. *Dipterocarpus tuberculatus*, ht 30 m, dbh 31 cm.
2. *D.tuberculatus*, ht 31 m, dbh 44 cm.
3. *Lithocarpus polystachyus*, ht 12.5 m; dbh 10, 12 cm.
4. *D.tuberculatus*, ht 25 m, dbh 32.5 cm.
5. *Aporusa villosa*, ht 10 m, dbh 9 cm.
6. *Shorea obtusa*, ht 27 m, dbh 39 cm.
7. *D.tuberculatus*, ht 32 m, dbh 45.5 cm.
8. *D.tuberculatus*, ht 30 m, dbh 52 cm.
9. *L.polystachyus*, ht 11 m, dbh 15.3 cm.

Figure 4.7a. Plan and canopy cover of plot A, (4 November 1987).



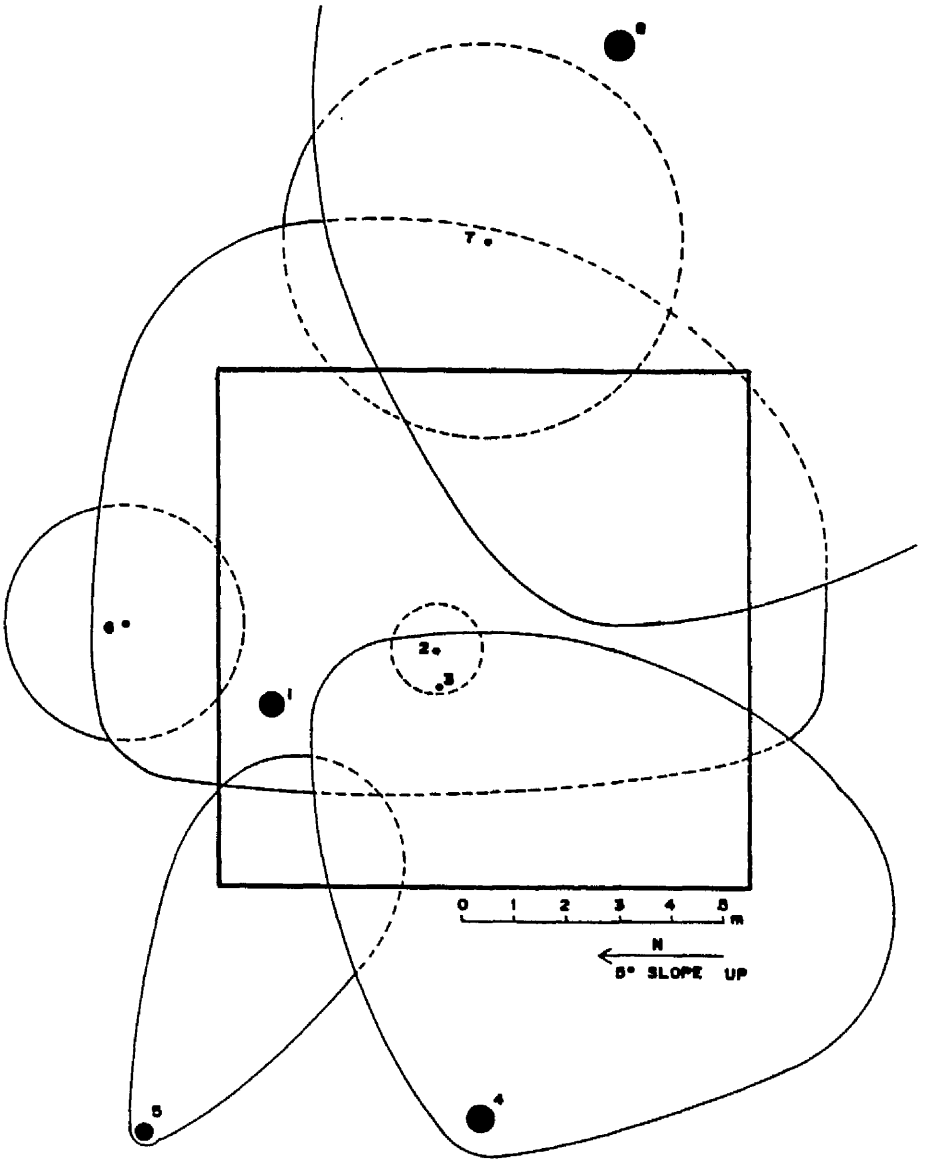
1. *Dipterocarpus tuberculatus*, ht 21 m, dbh 42 cm.
2. *D.tuberculatus*, ht 22 m, dbh 39.5 cm.
3. *D.tuberculatus*, ht 20 m, dbh 36.6 cm.
4. *Lithocarpus polystachyus*, ht 18 m, dbh 28 cm.
5. *Randia parvula*, ht 10 m, dbh 12 cm.
6. *Shorea obtusa*, ht 22 m, dbh 56.6 cm.

Figure 4.7b. Plan and canopy cover of plot B, (4 November 1987).



1. *Dipterocarpus tuberculatus*, ht 29 m, dbh 40 cm, with climber *Spatholobus parviflorus*, dbh 21 cm.
2. *Dillenia obovata*, ht 9 m, dbh 9 cm.
3. *Terminalia alata*, ht 15 m, dbh 14.5 cm.
4. *Shorea obtusa*, ht 17 m, dbh 16.5 cm.
5. *Anneslea fragrans*, ht 10 m, dbh 8.4 cm.
6. *D.obovata*, ht 9 m, dbh 10 cm.
7. *Quercus brandisiana*, ht 12 m, dbh 17 cm.
8. *Celtis tetranda*, ht 20 m, dbh 24.5 cm.
9. *Lithocarpus polystachyus*, ht 4 m, dbh 7 cm.
10. *T.alata*, ht 20 m, dbh 19.5 cm.
11. *L.polystachyus*, ht 7 m, dbh 10.6 cm.
12. *Aporusa villosa*, ht 12 m, dbh 18 cm.
13. *D.tuberculatus*, ht 30 m, dbh 45 cm.
14. *D.tuberculatus*, ht 31 m, dbh 49.3 cm.

Figure 4.7c. Plan and canopy cover of plot C, (4 November 1987).



1. *Shorea obtusa*, ht 27 m, dbh 47 cm.
2. *Mangifera* sp., ht 12 m, dbh 14.2 cm.
3. *S.obtusa*, ht 5 m, dbh 7.6 cm.
4. *Dipterocarpus tuberculatus*, ht 29 m, dbh 40.4 cm.
5. *S.obtusa*, ht 25 m, dbh 28.3 cm.
6. *S.obtusa*, ht 17 m, dbh 18 cm.
7. *Aporusa villosa*, ht 15 m, dbh 12.7 cm.
8. *S.obtusa*, ht 30 m, dbh 44 cm.

Figure 4.7d. Plan and canopy cover of plot D, (3 November 1987).

and could not be found around the Khao Nang Rum area.

Four 10 m x 10 m plots (A,B,C,D) were laid out. The initial point was chosen randomly from the marks along a stretched 50 m measuring tape, running from north to south. When plot A was established, two other plots (C,D) were then laid to the north of plot A at 6 m intervals - the gaps serving as fire breaks between plots. The fourth plot, (B), was taken from the west of plot A, as the flat area south of plot A did not have large trees. This was to ensure that all plots had a comparable number of top canopy trees, as leaf litter was a main source of fuel. Figs 4.6 and 4.7 show plans of the plot outlay and the canopy cover of each plot, with tree species, their respective heights, and diameters at breast height (dbh).

In addition, three sampling plots (S1, S2, S3) were laid out at three different corners of the area. These plots were used to sample ground cover biomass and moisture content monthly. Five 1 m^2 leaf litter collecting baskets were placed in plot B, which was to be a control plot, with four placed at each corner, and one right in the centre.

Although small trial burns were carried out for sustainability from 19 January 1988 onwards, it was not possible to sustain burns in this forest stand until 24 February 1988 (plot A). The experiment was repeated on plot D a month later on 25 March 1988. First rains then started to fall from the 8th of April, which left plot C unburned. Thus there are actually two control plots and two burned plots at different times for this association.

4.5.2 *Dipterocarpus* association 2, 460 m.a.s.l.

This is an almost pure stand of *Dipterocarpus tuberculatus*, lying along the eastern boundary of the *Dipterocarpus* 1 stand with a fairly sharp ecotone. Here, the canopy is much more open, about 30-40% in the wet season; the soil is stonier and the terrain is undulating. The ground cover ranges from 70-100%, 70% of which are grasses, with the following key species: *Heteropogon triticeus, Apluda mutica*, and *Eulalia bicornuta* Bor. Three small burns to test fuel sustainability were carried out here on all three grass species, in small flat areas, at the beginning of the fire season.

4.5.3 *Shorea* association 1, 460 m.a.s.l.

Apart from the *Dipterocarpus* 1 stand, this is the other site, at around 460 m.a.s.l., where monthly experimental burns were carried out all through the fire season (Fig.4.9). However, no permanent plots were

Figure 4.8. *Dipterocarpus* 1 stand (28 November 1987).

Figure 4.9. *Shorea* 1 stand, (17 January 1988).

set here because a single piece of flat land large enough to accommodate all the plots and fire breaks needed could not be found. Furthermore, the site is too near to the research station itself, and there is a major track cutting through the dry dipterocarp forest stand. Any research plot set here would be liable to unwanted human disturbances.

The land is gently undulating, with flat patches. The dominant trees are *Shorea siamensis* and some *Shorea obtusa*, which grow up to 20 m tall. It is an open, one to two storeyed formation, with a canopy cover in the rainy season around 30-40%. Ground cover ranges from 70-95%, with grasses comprising at least 70% of the cover. The grass element is dominated almost solely by *Heteropogon triticeus*, although patches of *Apluda mutica* are also found. The non-grass undergrowth comprises mainly the seedlings of *S.siamensis* and *S.obtusa*.

Burns carried out here were free burns without fire breaks. The fire was put out when the required measurements, such as the duration and spatial pattern of temperature, were completed. Three burns were effected on *Heteropogon triticeus* on 31 January 1988, 28 February 1988, and 23 March 1988. An additional burn was then made on *Apluda mutica* on 29 March 1988, to supplement the last *Heteropogon* burn which had to be put out before the measurement of the duration of maximum temperature was completed, as the fire was getting too dangerous. The whole area was later consumed by another fire, and only this patch of *Apluda mutica* remained unburned by 29 March 1988.

4.5.4 *Shorea* associations, below 460 m.a.s.l.

Four sites were burned in *Shorea* associations below 460 m.a.s.l. on 29 January 1988 in order to compare their sustainability with that of the *Dipterocarpus* 1 site, which would not sustain a burn even by late January. These experiments were free burns, without fire breaks.

1) *Shorea* association 2, burn No.1

This very open, one storey stand is at 270 m.a.s.l., with *Shorea siamensis* and *S.obtusa* as the dominant trees up to 15 m tall. Canopy cover on the day of the burn was 15%. The plot had a fairly dense ground cover of 90%, predominantly comprising grasses, with only 10% being seedlings of *S.siamensis* and *S.obtusa*. The grasses were *Heteropogon* spp, notably *H.triticeus*. A few dry *Cycas siamensis* were also present. Litter cover was not significant.

Full measurements of fire behaviour were taken at this site.

2) *Shorea* association 3, burn No.2

This formation is at 210 m.a.s.l. It is a two storeyed stand, with 15-20 m tall *Shorea siamensis* and *S.obtusa* as the dominant trees, although a few *Xylia kerrii* also occur. Canopy cover on the day of burn was 60%. Ground cover density was not uniform, and ranged from 50-70%, with grasses, notably *Heteropogon triticeus*, constituting 80% of the total cover. Non-grass undergrowth included seedlings of *S.obtusa*, *S.siamensis*, *Dillenia obovata*, and the leguminous shrub of a *Flemingia* sp., that was also common in the *Dipterocarpus* 1 site. Leaf litter was significant here, occupying 90% of the area, at 4-6 leaves deep.

Two small burns were tested on *Heteropogon triticeus*, measuring only the duration of maximum temperature.

3) *Shorea* association 4, burn No.3

This is another stand at 210 m.a.s.l. It had a canopy cover value of 15-20%, with *Shorea siamensis*, *S.obtusa*, and *Terminalia alata* as the dominant trees up to 15 m tall. Very dense *Heteropogon triticeus* formed nearly the entire ground vegetation, which covered 80-100% of the forest floor; only 10% of the ground cover comprised seedlings of the dominant trees. Leaf litter was hardly significant, covering only 50% of the area at 1-2 leaves deep.

One small burn was made here, again for measuring the duration of maximum temperature.

4) *Shorea* association 5, burn No.4

This stand is at 230 m.a.s.l. It is the most open of all the sites studied, with a canopy cover of only 5-10%. It was dominated by some *Shorea siamensis* and *S.obtusa* 10 m tall. Seedlings made up only 10% of the ground vegetation, which covered 90-100% of the area, being nearly completely dominated by the grass *Chrysopogon orientalis*. There was no leaf litter at the site of the burn. The duration of maximum temperature was measured.

4.5.5 Controlled leaf litter burns

As previously mentioned, these were experimental burns where leaf litter was deliberately arranged at different leaf depths. They were carried out on 19 January 1989, to supplement the data on the ground cover burns of the previous dry season. The different leaf depths represented litter accumulations which occur at different times in the dry season.

There were two sets of burns: one was done in the morning,

between 11.00-12.00 am; the other in the afternoon, between 13.00-14.30 pm. The leaf litter was arranged in 1.5 m x 1.5 m squares or in a 1 m x 3 m rectangle. Duration of maximum temperature was measured.

4.6 Social survey

In addition to the detailed ecological research, an attempt was also made to conduct some social surveys on the knowledge and general perceptions of dry dipterocarp forest fires, including the causes of fire and seasonal timing; the impact of different fire regimes on the ecosystems concerned; and questions relating to sustainable fire management policy. Two groups of respondents were chosen. The first was based on a mailing questionnaire, aimed at various groups and individuals involved in the field of conservation, or management of 'natural' land. Most of this group were well-educated people, often living in Bangkok or other urban areas. Of the 200 questionnaires sent out, 157 were returned (78.5%).

The second batch was aimed at villagers living in or near to Huai Kha Khaeng Wildlife Sanctuary. Ideally, information relating to forest fire situations and local practices would be best obtained through participatory observation and by asking questions relating to specific fire events in a given area. But as the villages were far from the experimental sites, and scattered along the sanctuary border (Fig.4.4), such a study was not practical without private transportation. There was also a question of the time which would be needed to gain enough trust to participate in such an illegal activity as lighting forest fires. A compromise was therefore made, and a structured interview-questionnaire was opted for as the study format, posing similar questions to those in the first survey, but with some additional enquiries about the local situation, particularly concerning the history of forest management and villagers' activities during the wet and dry seasons. The chosen respondents were often old or middle-aged men who were thought to know 'the way of the forest'. There were only one or two such people in each village. This survey was done within 12 days while a 4-wheel drive vehicle was available for my use. Only 19 questionnaires from 17 villages were completed.

Because the number of respondents in the second survey was so limited, and because it was decided to narrow the focus of the thesis primarily onto the ecological observations, the social survey was not analysed in full. However, reference is made to these studies wherever appropriate, especially in the later discussion of forest fire management

in Thailand (Section 8.3).

4.7 Problems encountered in the field

It was unfortunate that 1988 turned out to be one of the wettest years on record at Khao Nang Rum Research Station (Section 5.1). As a result, experimental burns on the permanent plots in the *Dipterocarpus* 1 stand could not start until as late as 24 February, and stopped just over a month later. This short fire season gave rather less variation in different times of burn than it was hoped for. Moreover, a heavy local flood in September and October made the site inaccessible during those two months, and consequently there are also missing data on vegetation recovery.

In addition, an animal track crissed-crossed the *Dipterocarpus* 1 stand, linking up two salt licks. This brought large grazers, such as elephants and gaur, to the plots. These often disturbed the ground vegetation, particularly in plot B where litter collecting baskets were placed. The baskets were alien, human-made elements, which the elephants dismantled regularly. In January, all the baskets were trampled. Thus, data on leaf litter biomass is missing for that important month, when a considerable litter fall began to take place.

The study of fire behaviour requires efficient team work. This was not always available. In most of the burns, only two people were present, including myself. It is regretted that not as many relevant variables could be recorded as one would have wished.

CHAPTER 5.

EXPERIMENTAL RESULTS I: conditions for burns and fuel sustainability

5.1 Weather and the low fire potential of 1987-1988

At Khao Nang Rum Research Station, the dry season generally begins in November and lasts until April or May, when the Southwest monsoon usually returns, persisting through to October or early to mid-November, with an average precipitation of ≤1500 mm per annum. During the dry season, the Northeast monsoon, which is locally called the 'mango rains', often falls in February and March, with an average rainfall of 35-40 mm $month^{-1}$ (see Table 5.1, Fig.5.1).

The research year (October 1987-November 1988), however, experienced the highest annual rainfall (>2000 mm) in the past 7 years, 1983 being the only comparable year. Moreover, the Southwest monsoon ended late in 1987, with as much as 170 mm of rain falling in November, finishing on the 29th of the month, which compares with a mean of 70 mm for November in an average year. The start of the dry season was then interrupted by an

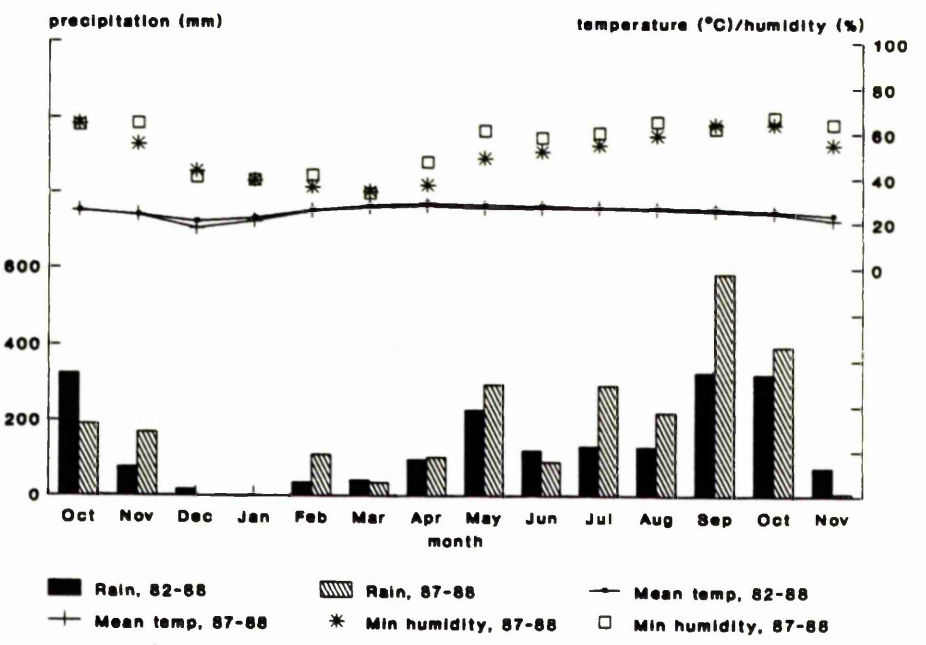


Figure 5.1. Weather data, Khao Nang Rum Research Station: comparison between the study year (1987-1988) and other years (1982-1988). (Relative humidity data from Nakorn-sawan province).

Table 5.1. Annual rainfall (mm), Khao Nang Rum Research Station, Uthaithani province.

MONTH	RAINFALL (mm)	
	mean1982-88	1987-88
Oct	323.8	190.9
Nov	76.6	169.9
Dec	17.4	0
Jan	1.9	0
Feb	35.2	110.4
Mar	42.6	36.3
Apr	97.5	104.9
May	229.4	296
Jun	122.9	91.8
Jul	133.8	295.8
Aug	132.6	223.5
Sep	329.8	585.6
Oct	323.8	395.9

YEAR	RAINFALL (mm)
1982	1130
1983	2004
1984	1204
1985	1472
1986	1528
1987	1318
1988	2148
mean	1544

unusually heavy Northeast monsoon in February 1988, with 110 mm of rainfall. Finally, the 1988 Southwest monsoon began in early April, and was also exceptionally heavy, resulting in severe flooding in valleys and plains in September and October, during which period the site became inaccessible.

In general, the coldest months, with a mean minimum temperature of 13°C in the shade, are December (mean 1982-88 = 20.5°C) and January (mean 1982-88 = 22° C). The latter month sees temperature picking up, and it continues to rise through February and March to reach a peak in April, with a mean maximum temperature of 34° C in the shade (mean 1982-88 = 29°C; Table 5.2, Fig.5.1).

Mean temperature throughout the study year was generally about 1° C lower than in an average year, and the mean temperature of 17° C was particularly low in December (mean 1982-88 = 21°C). Nevertheless, throughout any year, there is always a time of day when temperature rises

Table 5.2. Air temperature (at Khao Nang Rum Research Station, Uthai-thani province) and relative humidity (for Nakorn-sawan province).

MONTH	MEAN 1982-88						1987-88					
	Temperature (°C)			Humidity (%)			Temperature (°C)			Humidity (%)		
	mean			mean								
	max	min	$\bar{x}$	max	min	$\bar{x}$	max	min	$\bar{x}$	max	min	$\bar{x}$
Oct	28	21	25	95	64	83	30	21	25	96	63	82
Nov	26	18	23	93	55	76	26	21	23	95	64	83
Dec	25	13	21	89	43	68	23	12	17	90	40	68
Jan	27	13	22	85	39	63	28	13	21	88	39	65
Feb	32	16	26	86	36	60	31	19	25	86	41	63
Mar	34	18	28	85	34	58	36	19	27	85	33	58
Apr	34	21	29	84	37	61	34	22	28	88	47	68
May	32	22	28	88	49	70	32	22	27	94	61	80
Jun	32	22	28	88	52	72	31	22	27	93	58	77
Jul	30	22	27	90	55	74	32	22	27	94	60	79
Aug	30	22	27	93	59	78	30	22	26	95	65	82
Sep	29	21	26	95	64	82	30	21	25	96	62	81
Oct	28	21	25	95	64	83	28	21	25	96	67	84

above 24°C, which is the temperature when fire is found to occur most commonly (Mather 1978a). However, relative humidity showed a different pattern (data from Nakorn-sawan province). Mather (1978a) found fire to burn usually when humidity drops below 50%. If that is taken as the criterion, only 5-6 months of the year, with a minimum relative humidity of <50%, have a potential for a burn. This period stretches from December, when mean relative humidity begins to drop, to the lowest value in March (mean = 58%; mean minimum = 34%), and rises again with the return of the rains, until April or May, after which time minimum relative humidity always exceeds 50%. Mean relative humidity is usually highest towards the end of the rainy season, in September and October (mean = >80%; mean minimum = >60%). During the year of study, overall relative humidity was slightly higher than in an average year, although the values for the dry season (December-March) were generally comparable.

Based on 1985-1989 weather data from Lansak district, near the Head Quarters of the Wildlife Sanctuary, mean wind speed is often below 3 knots during most part of year, with the lowest value of just over 1 knot in October. An exception is from February to April, when wind speed increases up to over 5 knots in March (see Table 5.3, Fig.5.2). Wind speed

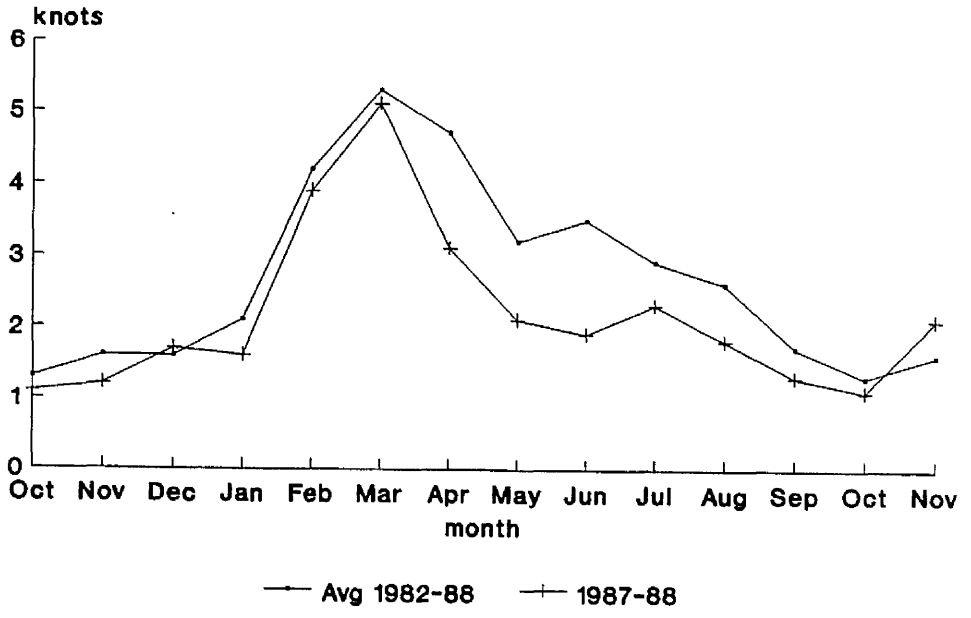


Figure 5.2. Wind speed (knots), Lansak district, Uthai-thani province: comparison between the study year (1987-1988) and other years (1982-1988).

MONTH	MEAN1982-88	1987-88
Oct	1.3	1.1
Nov	1.6	1.2
Dec	1.6	1.7
Jan	2.1	1.6
Feb	4.2	3.9
Mar	5.3	5.1
Apr	4.7	3.1
May	3.2	2.1
Jun	3.5	1.9
Jul	2.9	2.3
Aug	2.6	1.8
Sep	1.7	1.3
Oct	1.3	1.1

Table 5.3. Wind speed (knots), Lansak district, Uthai-thani province: comparison between the study year (1987-1988) and other years (1982-1988).

during the study year was generally lower than on average, usually being below 2 knots, although the speed increased during the three dry season months, with March reaching its usual 5 knots. This relatively stronger March wind is called '*lom wow*', or 'kite wind', in Thai, and it marks the season for the kite-fighting festival.

Taken from Nakorn-sawan province, the detectable number of dry thunder days in April was above average at 6 days. At least one day of dry thunder occurred in February and March.

On the whole, therefore, the study year (October 1987-November 1988) presented a lower potential for burns than in an average year, with higher rainfall in the dry season, and often lower mean temperatures and higher mean relative humidity.

5.2 Fuel characteristics

In this study, three main categories of fuel were regularly recorded (see Section 4.2.2), namely: grasses, non-grass ground cover, and leaf litter. The characteristics noted were internal moisture content, biomass, leaf depth and ground cover height, surface fuel cover value, and grass arrangement. All measurements were taken from the *Dipterocarpus* 1 stand where permanent experimental plots were set up.

5.2.1 Fuel moisture content

Table 5.4 and Fig.5.3 show how the moisture content of both the ground cover and the soil were directly influenced by the amount of rainfall received. Thus, their moisture content began to drop markedly in December, with the non-grass ground cover reaching its lowest at 48.6% by the end of January 1988. The moisture content of both the grasses and the soil were also low in January, although the very lowest values were recorded at the end of February, with that of the grasses reaching 35.6%, and the soil moisture content dropping to 1.9% for the surface soil from ground-level to 5 cm deep, and 3% for soil from 5-15 cm deep.

Unlike the grasses and soil, the moisture content of the non-grass ground cover began to increase noticeably by the end of February, probably in response to the falling of the Northeast monsoon earlier in the month. Generally, however, a marked increase of moisture content of both ground cover and soil occurred in April, with the arrival of the Southwest monsoon. During the rainy season, moisture content of the ground cover remained at around 60-70%, and in contrast to the dry season, soil moisture content was higher at the surface from ground-level to 5 cm

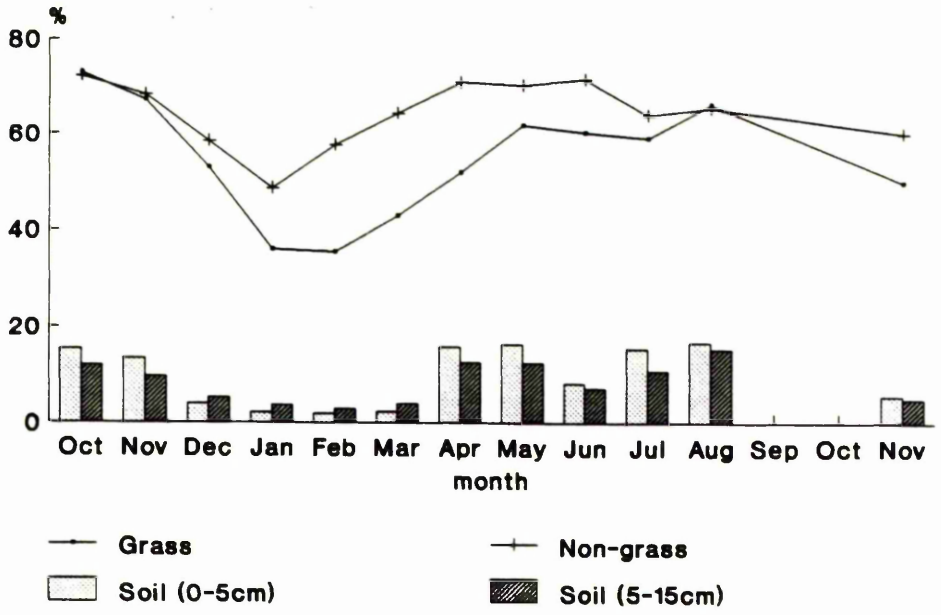


Figure 5.3. Moisture content of ground cover and soil, *Dipterocarpus* 1 stand, 1987-1988.

MONTH	MOISTURE CONTENT (%)			
	Ground cover		Soil	
	grass	non-grass	0-5cm	5-15cm
Oct	73	72.3	15.3	12
Nov	67.3	68.4	13.4	9.7
Dec	53	58.5	4	5.3
Jan	36.2	48.6	2.2	3.7
Feb	35.6	57.8	1.9	3
Mar	42.9	64.4	2.4	4
Apr	52	71	15.8	12.6
May	62	70.5	16.3	12.5
Jun	60.4	71.7	8.3	7.2
Jul	59.2	64	15.5	10.8
Aug	66.4	65.6	16.8	15.3
Nov	49.9	60.2	5.7	5

Table 5.4. Moisture content of soil and ground cover from unburned plots, *Dipterocarpus* 1 stand, 1987-1988.

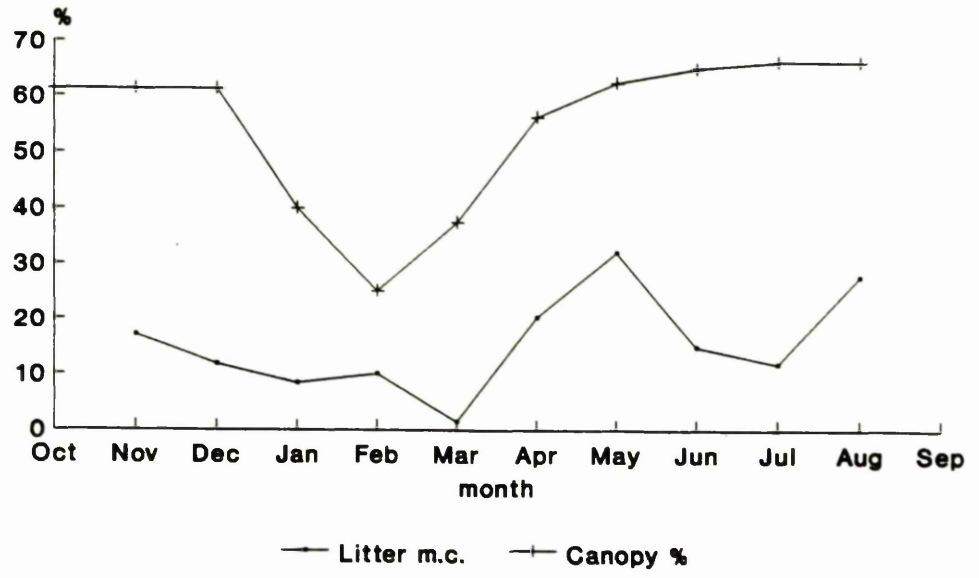


Figure 5.4. Moisture content of leaf litter and canopy cover, *Dipterocarpus* 1 stand, 1987-1988.

MONTH 1987	LEAF LITTER BIOMASS ($g\ m^{-2}$)	LEAF LITTER DEPTH	LEAF LITTER COVER (%)	LEAF LITTER MOISTURE CONTENT (%)	CANOPY COVER (%)
Oct		1	30		61
Nov		2	38	17	61
Dec	18.6	2	38	11.8	61
Jan	-	2	80	8.4	40
Feb	356.3	3	85	10	25
Mar	425.8	5	95	1.5	38
Apr	52.7	5	95	20.2	56
May	62.8	5	95	32	63
Jun	44.5	5	95	14.9	65
Jul	21	5	95	11.8	66
Aug	11.2	5	95	27.7	66
Nov 1988	-	4	70	-	65

Table 5.5. Canopy cover, leaf litter accumulation and its moisture content from unburned plots, *Dipterocarpus* 1 stand, 1987-1988.

deep (mean = 14.5%) than from 5-15 cm deep (mean = 11.4%) during the wet months. Furthermore, the soil moisture content fluctuated most readily with rainfall, as seen in June 1988, when a drop of precipitation from almost 300 mm month^{-1} down to 92 mm month^{-1} brought an immediate decrease in the soil moisture content to around 8% at both depths.

Although the moisture content of leaf litter also depends on the amount of rainfall received, as may be seen in the low values for June and July, it seems to be the amount of direct sunlight through the forest canopy that ultimately determines the dryness of leaf litter. Table 5.5 and Fig.5.4 show how the moisture content of the leaf litter at 1.5% was the lowest by the end of March, one month after the period of the thinnest canopy cover (25%) at the end of February.

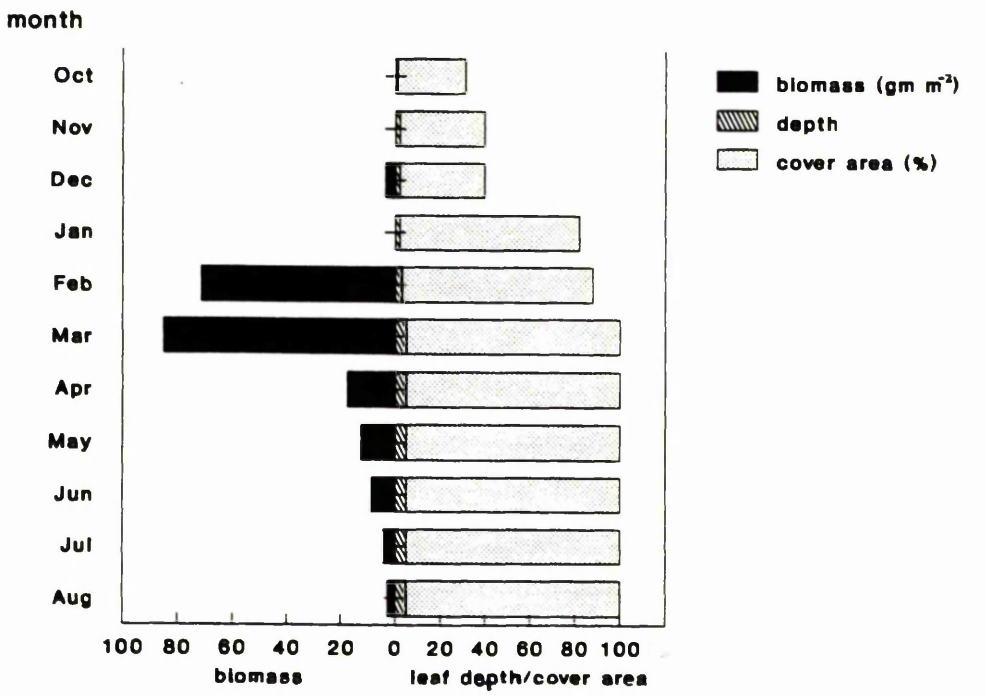
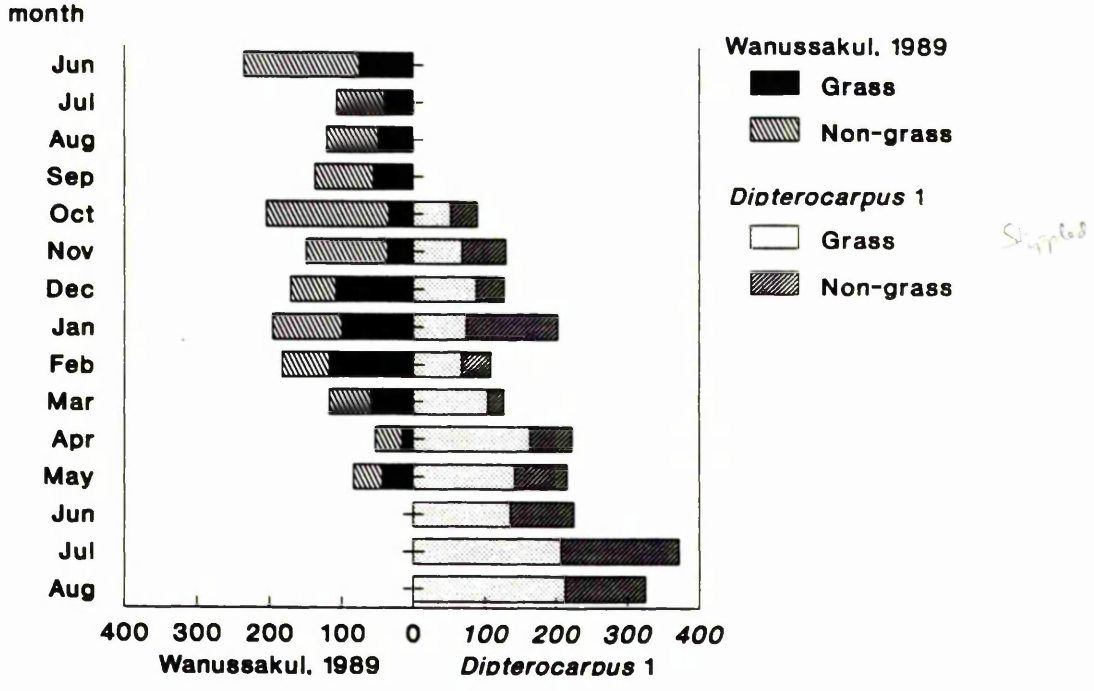


Figure 5.5. Quantity of leaf litter in terms of biomass, leaf depth and cover area, *Dipterocarpus* 1 stand, 1987-1988.

5.2.2 Fuel biomass and cover

5.2.2.1 Leaf litter

March was also the month when the leaf litter depth, biomass, and cover percentage were at their highest in the *Dipterocarpus* 1 stand (see Table 5.5, Fig.5.5). A period of considerable leaf-shedding began sometime in the second week of January 1988, although data on leaf litter biomass is absent for this month because the litter collecting baskets were all destroyed by elephants. However, in contrast to a December biomass value of almost 4 g m^{-2}, over 70 g m^{-2} fell in February, and 85 g m^{-2} continued to fall in March, by which time new leaves had been flushed to give an average canopy cover of around 38%. Thus, the period of the thinnest canopy cover (February) does not necessarily coincide with the period of highest leaf litter fall (March). Likewise, leaf litter depth reached its highest from 1 leaf deep in November to 5 leaves deep in March, and the leaf litter cover value attained 95% in March, in contrast to a mean value of <40% in December 1987.



Right: data from the *Dipterocarpus* 1 stand, permanent plots of the thesis.
Left : data from the stand studied by Wanussakul (1989).

Figure 5.6. Biomass of grass and non-grass ground cover species in two neighbouring *Dipterocarpus* association stands in Khao Nang Rum Research Station, June 1987 - August 1988.

Table 5.6. Ground cover biomass (g m^{-2}), *Dipterocarpus* associations, May 1987 - November 1988.

MONTH	WANUSSAKUL (1989)			PRESENT STUDY		
	grass	non-grass	total	grass	non-grass	total
1987						
May	26.9	88.3	115.2			
Jun	75.8	146.7	222.5			
Jul	40.3	66.4	106.7			
Aug	48.6	71.5	120			
Sep	55.3	81.6	136.9			
Oct	33.4	170.5	203.9	53	37	90
Nov	35.6	113.4	149	68	61.5	129.5
Dec	108.5	61.7	170.2	88	39	127
Jan	99.6	95.8	195	74.3	128.5	202.8
Feb	116.8	66	182.8	67.6	41.6	109.2
Mar	59.2	57.7	116.9	104.5	22.7	127.2
Apr	15.4	37.5	52.9	163	58.9	221.9
May	43.8	39.7	83.5	141.4	74.1	215.5
Jun				135.4	89.8	225.2
Jul				206.2	165.5	371.7
Aug				212.5	112.9	325.4
Nov				211.8	104.8	316.6
1988						

5.2.2.2 Ground cover

Part of the data on ground cover biomass is taken from Wanussakul's (1989) M.Sc study on a *Dipterocarpus* association situated near to my own experimental plots and to which it bears a fair resemblance. His data, based on extensive grid sampling of 60 x 1 m^2, was collected from May 1987 to May 1988, thus overlapping my study by some eight months. From both Wanussakul's and my own records, where fire was excluded, ground cover biomass values tended to fluctuate throughout the year (see Table 5.6, Fig.5.6). In the case of the non-grass biomass, the fluctuation was so great that no distinctive pattern appeared. This probably partly reflects the high inconsistency of the ground cover distribution in the *Dipterocarpus* association. Neither do the patterns from the two studies of grass biomass correspond. In my own data, there seems to be a tendency for a higher biomass build up in the rainy months (April 88-November 88), with a mean value of 178 g m^{-2} $month^{-1}$ (range = 135-213 g m^{-2}), in contrast to a lower mean biomass of 81 g m^{-2} $month^{-1}$ during the dry season months of November 1987 to March 1988 (range = 68-105 g m^{-2}). On the other hand, Wanussakul's data shows a high grass biomass to occur from the early to mid dry season months (December 1987-

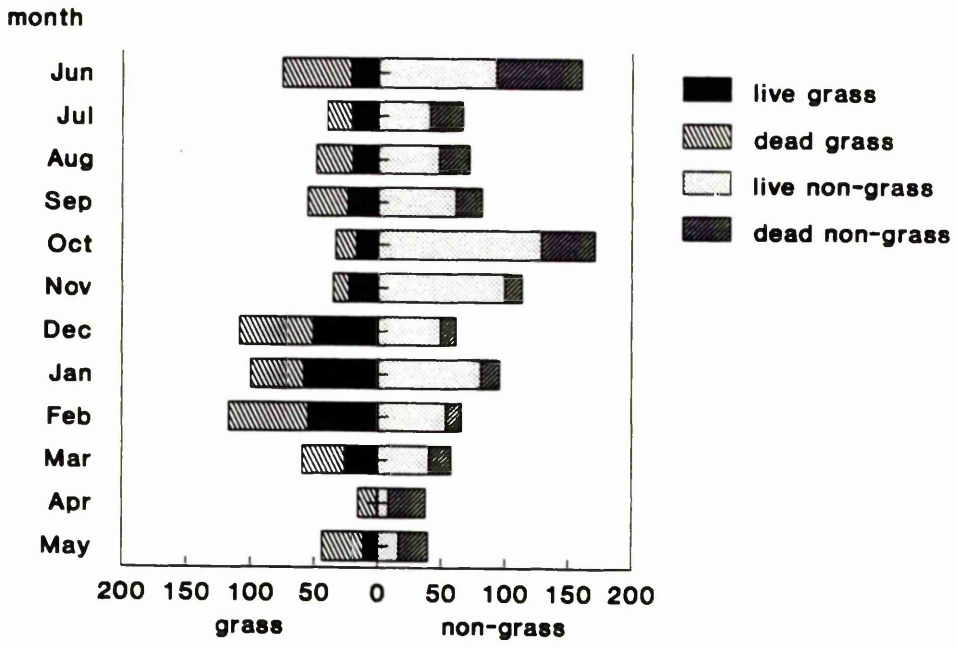


Figure 5.7. Live and dead biomass of grass and non-grass ground cover species in *Dipterocarpus* association stand studied by Wanussakul (1989), June 1987 - May 1988.

MONTH	LIVING BIOMASS		DEAD BIOMASS	
	grass	non-grass	grass	non-grass
1987				
May	4.5	12.3	22.4	76
Jun	22	92.9	53.8	67
Jul	20.8	40.4	19.5	26
Aug	20.6	47.8	28	23.7
Sep	24.3	60.8	31	20.8
Oct	17.5	128	15.9	42.5
Nov	23.3	99.6	12.3	13.8
Dec	51.3	48.8	57.2	12.9
Jan	58.6	81.2	41	14.6
Feb	55.2	53.2	61.6	12.8
Mar	26.2	40	33	17.7
Apr	0.8	8.3	14.6	29.2
May	11	16.5	32.8	23.2
1988				

Table 5.7. Live and dead biomass (g m^{-2}) of ground cover in *Dipterocarpus* association, May 1987-1988 (from Wannassakul 1989).

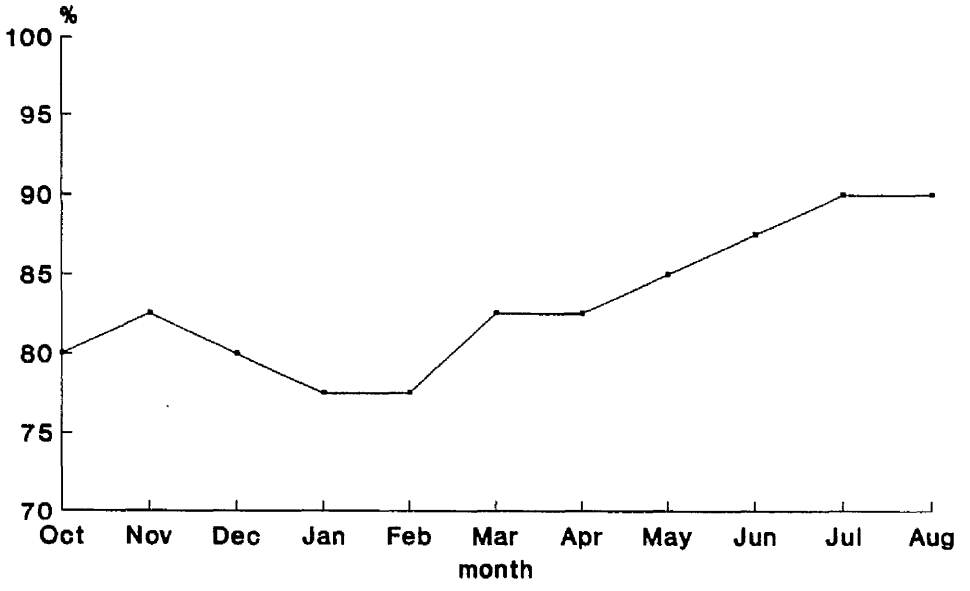


Figure 5.8. Mean ground cover in the unburned plots of the *Dipterocarpus* 1 stand, 1987-1988.

MONTH 1987	GROUND COVER (%)
Oct	80
Nov	83
Dec	80
Jan	78
Feb	78
Mar	83
Apr	83
May	85
Jun	88
Jul	90
Aug	90
Nov 1988	90

Table 5.8. Mean ground cover (%), unburned plots, *Dipterocarpus* stand 1, 1987-1988.

February 1988), with a mean value of 108 g m^{-2} $month^{-1}$ (range = 100-117 g m^{-2} $month^{-1}$), while the mean for the rest of the year (June-November 1987, March-May 1988) is 49 g m^{-2} $month^{-1}$ (range = 15-76 g m^{-2} $month^{-1}$). However, it is worth noting that the wet season (April-October) of 1987 received

less rainfall (996 mm) than that of 1988 (1994 mm) by almost 1000 mm, which could partly explain the generally much higher wet season biomass in my 1988 record (mean = 178 g m^{-2} $month^{-1}$) than in Wanussakul's 1987 collection (mean = 49 g m^{-2} $month^{-1}$).

Wanussakul's (1989) data is further divided into living and dead biomass (Table 5.7, Fig.5.7). The difference between the biomass values of living and dead grass is little, with a mean of 33 g m^{-2} $month^{-1}$ and 28 g m^{-2} $month^{-1}$ or 55% and 45% respectively. In contrast, living biomass forms 70% of the total mean biomass value of the non-grass ground cover, with a mean of 60 g m^{-2} $month^{-1}$, while the mean value for dead biomass is 25 g m^{-2} $month^{-1}$. Around April is about the only time when the dead biomass of the non-grass species has a greater value than the living portion, at 28 g m^{-2} $month^{-1}$ and 9 g m^{-2} $month^{-1}$ respectively. In general, therefore, the greater proportion of grasses in the undergrowth coverage, with a high proportion of dead biomass, the higher the potential for a burn.

In the case of the *Dipterocarpus* 1 stand, an initial mean of 47% of total ground cover composition at the end of October 1987 were grasses, with the remaining 53% being non-grass species. In terms of the actual ground cover area of around 80%, grass and non-grass growth covered 38% and 43% respectively. The presence of grass is thus clearly significant in this formation.

With rain continuing to fall until the end of November 1987, this month saw an overall slight increase in ground cover percentages by 2-5% (see Table 5.8, Fig.5.8). But as the dry season began, mean ground cover values dropped back down again, and remained around 80%, or slightly below, until the end of February. In unburned areas, mean ground cover values revived by March, and steadily increased to around 90% by the end of July through to November 1988. This pattern reflects the influence of rainfall on ground vegetation coverage, with relatively lower values during the dry season as plants wither and many deciduous members of the undergrowth shed their leaves.

5.2.3 Ground cover height and fuel arrangement

Mean ground cover height, which was measured without stretching or touching the plants to represent the vertical distribution of the fuel, was also reduced during the dry season, noticeably in certain grass species which did not remain upright at this time, such as *Heteropogon triticeus*, and to a lesser extent, *Sorghum nitidum* (see Table 5.9, Fig.5.9). With the exception of *Imperata cylindrica*, most grass

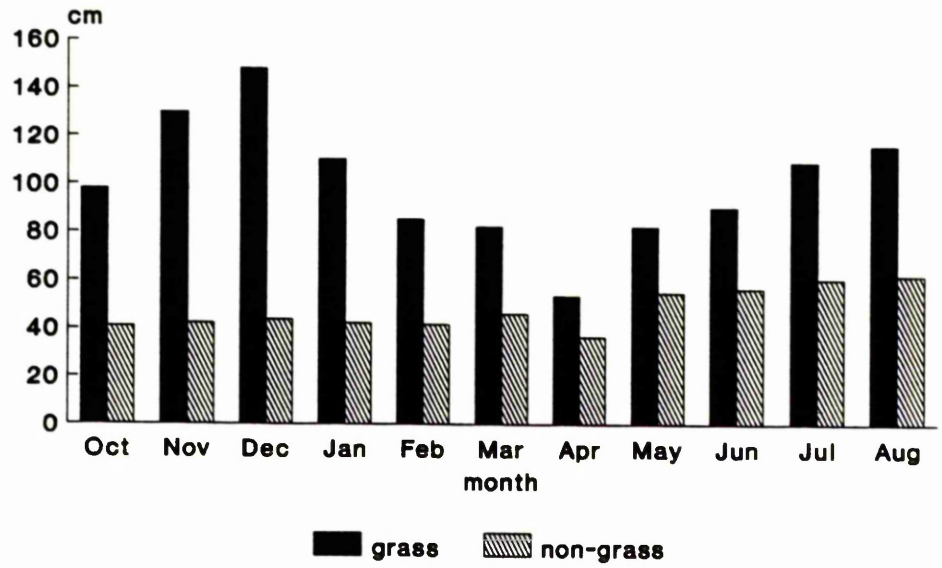


Figure 5.9. Mean height (cm) of grass and non-grass ground cover species in the unburned plots of the *Dipterocarpus* 1 stand, 1987-1988.

MONTH	HEIGHT (cm)	
	GRASS	NON-GRASS
1987		
Oct	98	40.9
Nov	129.8	42.3
Dec	148.2	43.7
Jan	110.4	42.2
Feb	85.4	41.8
Mar	82.3	46
Apr	53.6	36.7
May	82.2	55.2
Jun	90.3	56.6
Jul	109.2	60.6
Aug	115.9	62
Nov	130.8	60
1988		

Table 5.9. Mean ground cover height (cm), unburned plots, *Dipterocarpus* stand 1, 1987-1988.

Table 5.10. Grass height (cm) and arrangement in unburned plots, *Dipterocarpus* 1 stand, 1987-1988.

MONTH	*Heteropogon triticeus*	*Apluda mutica*	*Sorghum nitidum*	*Imperata cylindrica*
Oct	119 cm standing	98 cm standing	86 cm standing	96 cm standing
Nov	148 cm standing	148 cm standing	93 cm standing	95 cm standing
	SW monsoon ended on the 29th			
Dec	152 cm standing (flowering)	173 cm standing (flowering)	132 cm standing (flowering)	91 cm standing
Jan	60 cm mostly fallen	161 cm standing	99 cm mostly stand	91 cm standing
	Elephants trampled plots on the 16th			
Feb	47 cm all fallen	138 cm standing	88 cm ≈1/3 fallen	84 cm standing
	NE monsoon started from the 4th			
Mar	44 cm all fallen	127 cm standing	71 cm ≈1/3 fallen	83 cm standing
Apr	57 cm standing (new growth)	117 cm standing (new & old)	60 cm standing (new growth)	85 cm standing (new & old)
	SW monsoon started on the 6th; Elephants & gaur on plots			
May	73 cm standing	90 cm standing	74 cm standing	102 cm standing
Jun	85 cm standing	99 cm standing	79 cm standing	100 cm standing
Jul	92 cm standing	114 cm standing	98 cm standing	107 cm standing
Aug	100 cm standing	129 cm standing	107 cm standing	106 cm standing
	Elephants visited plots			
Nov	130 cm standing	138 cm standing	143 cm standing	71 cm standing
	Elephants and gaur visited plots			

Flood made site inaccessible in September & October 1988.

Figure 5.10. The arrangement of two different grass species after the arrival of the Northeast monsoon on 4 February 1988.

Fig.5.10a. *Apluda mutica* L.

Fig.5.10b. *Heteropogon triticeus* (R.Br.) Stapf.ex Craib

species studied reached their tallest in December when they flowered after the rainy season, and at the same time began to lose their moisture content. By January, the collective moisture content of all the grass species had dropped from an initial mean of 73% in October to 36%. At this point, more than 80% of the *H.triticeus* stems had fallen, while other grass species remained largely standing. It is not known if the loss of moisture content at this level could directly influence the cellular structure of *H.triticeus* to collapse so extensively on its own, but, unlike the other species, *H.triticeus* stalks did not spring back to the original upright position after they were trampled down by elephants in mid January (see Table 5.10). The heavy rain drop impact of the Northeast monsoon in February then further flattened the *H.triticeus*, and to some extent, the *Sorghum nitidum*. This phenomenon is best seen in the open *Shorea* association with *H.triticeus* as the single dominant grass, as is shown in Fig.5.10b. Grass arrangement remained the same for each species through the rest of the dry season, until new growth gregariously appeared in April, when elephants, gaur and other herbivores, frequented the site in large numbers. Despite this heavy disturbance, all the grasses stood upright, with a mean collective moisture content of 52%.

It is, therefore, likely that moisture, which often provides turgidity within plant cells, plays an influential role in grass fuel arrangement. However, the arrangement of each grass species ultimately depends on the strength of its structural make up, and probably the silica content of its cell walls. This will be further discussed and exemplified in Chapter 6 when the significance of grass arrangement arises again.

Mean height of the dominant non-grass ground cover also decreased slightly in the dry season, as some died back and some shed leaves (Table 5.9, Fig.5.9). However, on unburned plots, the lowest mean height of 37 cm was recorded in April. Perhaps the presence of large grazers, presumably attracted by the new growth, was partly responsible for this. The impact of the early Southwest monsoon may also help to flatten and to disintegrate the dry biomass even further, at a time when the new plants were still small.

5.3 Fire occurrence

Table 5.11 reviews the dates and duration of fire and some other related events in Khao Nang Rum Research Station during the study year. The significance of some of these timings will be discussed fully at the end of the thesis. This section will only be concerned with fire

Table 5.11. Fire occurrence and dry season rains around Khao Nang Rum Research Station, 1987-1988.

DATE	RAIN	FIRE		
		Shorea associations		*Dipterocarpus* associations
		<460 m.a.s.l.	460 m.a.s.l.	460 m.a.s.l.
Nov 29	last SW mon -soon			
Dec	no rain			
Jan 6		first fire in an open formation, incomplete burn		
24 - 29		fires common in open formation, complete burn some fire in more mesic formation, incomplete burn		
Feb 4-9	rain			
17 - 18	rain			
by 23		30-40% roadside formations burned		
25			first fire, (all formations are open)	
27 - 29	rain & hail			
Mar 7	rain			
9-19		many fires, second burn on some areas		
23 - 29			many fires	many fires
Apr 6	first SW mon -soon			

occurrence.

No official record is kept of fire occurrence in the Wildlife Sanctuary. The data collected here is therefore limited to the immediate area within about 4-5 km radius from the research station (460 m.a.s.l.) and along the sides of the 16 km road from the sanctuary's eastern border at the Head Quarters to the research station (<460 m.a.s.l.). Fire events were recorded through direct observation, and through regular check-up interviews with the sanctuary rangers.

The earliest fires observed were on the very open *Shorea* association at 270 m.a.s.l. These occurred in the second and the third week of January, after the last downpour on 29 November 1987. These earliest fires were few and small, and generally they did not spread much more than around 6 m. The burns were very incomplete, with most grass blades remaining intact. Towards the last week of January, however, burns were rather common in this area where combustion was more or less complete, and the fire spread well. At the same time, poorly sustained and incomplete burns began to occur in closer and more mesic *Shorea* associations below 460 m.a.s.l.

The fire season was then halted temporarily by the outbreak of a heavy Northeast monsoon in the first week of February, and it was not until 25 February that the very first fire was seen at 460 m.a.s.l. By this time, up to approximately 40% of road side *Shorea* associations below 460 m.a.s.l. had burned.

Fire occurrences, however, were not very extensive until the second week of March, coinciding with an increase in the mean wind speed from 3 to 5 knots (Nakorn-sawan data). By the 19th of March, most of the road side area below 460 m.a.s.l. had burned, some for the second time since January. At 460 m.a.s.l., in the vicinity of the research station, extensive and numerous fires occurred from 23-29 March, but they were almost always self-extinquished by relatively cooler air around 8.00 pm in the evening. Fires then ceased to occur when the fuel supply became exhausted, which was about one week before the arrival of the Southwest monsoon on the 6th of April.

5.4 Ignitability and sustainability tests on fuel moisture content

The method employed for this test is described in Section 4.2.2.2, using 10 leaf samples of each of the following fuel categories from the *Dipterocarpus* 1 stand, namely: non-grass ground cover, grasses, and leaf litter.

The results (Tables 5.12, 5.13; Figs 5.11, 5.12) clearly show that moisture content is strongly correlated with fuel sustainability, and to a much lesser extent, with fuel ignitability.

5.4.1 Ignitabilty

Grasses and leaf litter were always readily ignited throughout the testing period (November-May), and non-grass ground cover never took more than a few seconds (scale point 4). Table 5.12 shows that the moisture content of non-grass species at the level when they may be ignited in an instant (scale point 5) is around 65-70%, which is only a little lower than the highest moisture content of 72% that occurs in October (Table 5.4). It is possible, therefore, that the internal moisture content of dry dipterocarp forest fuels has no, or little influence, on its ignitability.

I.value	SCALE POINT*				
	1	2	3	4	5
Non-grass moisture content (%)				72 71.1 64.4	 70.5 68.4 58.5 57.8 48.6
Grass moisture content (%)					73 67.3 62 53 52 42.9 36.2 35.6
Leaf litter moisture content (%)					32.1 20.2 17 11.8 10 8.4 1.5

* see Section 4.2.2.2

Table 5.12. Fuel ignitability in relation to moisture content.

Table 5.13. Fuel sustainability in relation to moisture content.

S.value	SCALE POINT*				
	1	2	3	4	5
Non-grass moisture content (%)	72 71.1 70.5 68.4 64.4 58.5	57.8 48.6			
Grass moisture content (%)	73 67.3 62 53 52	42.9 36.2	35.6		
Leaf litter moisture content (%)	32.1		20.2 17	11.8 10 8.4	1.5

* see Section 4.2.2.2

5.4.2 Sustainability

As seen in Table 5.13, in all fuel types, sustainability increases with the decrease of fuel moisture content. Critical values of moisture content for the point when fire may be fully sustained, however, differ for different fuel types.

To sustain fire beyond the flame point (scale point 2), the critical moisture content for the non-grass fuels is 58%, while for the grasses it is somewhat lower, but not significantly different, at around 45-50%. On the other hand, leaf litter still burns at the flame point (scale point 1) when the moisture content is as low as 32%. Meanwhile, grasses sustain over 5 cm, or over a quarter of leaf length (scale point 3), when moisture content is below 36%. The critical value at this level is not known for the non-grass fuels which never reached a moisture content below 48% during the study year, and the grasses never fell below 35%. Leaf litter was the only fuel type that almost completely dried up,

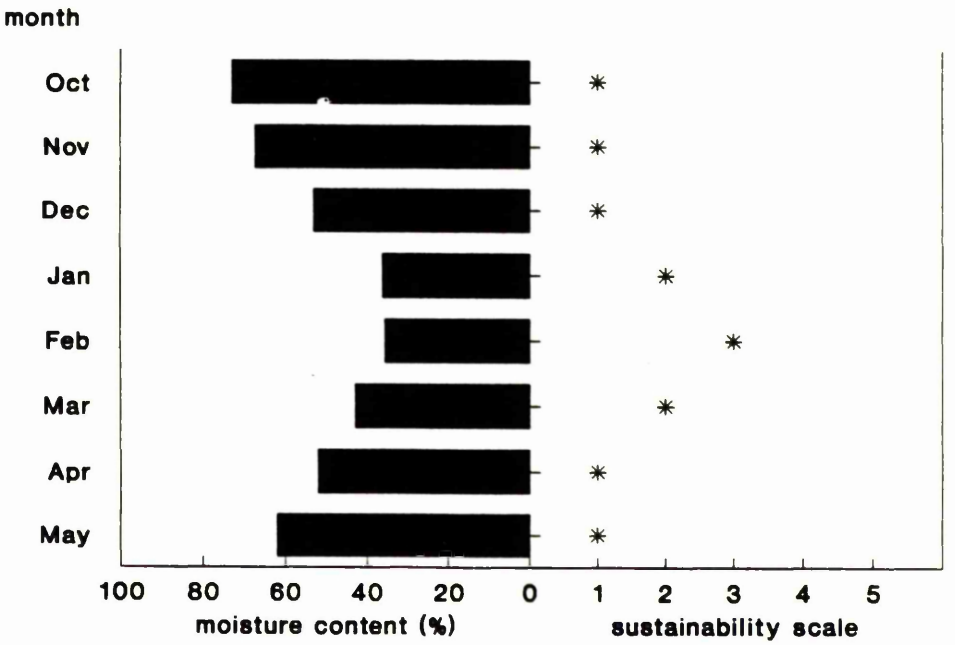


Figure 5.11a. Sustainability of grasses in relation to moisture content, *Dipterocarpus* 1 stand, October 1987 - May 1988. (For sustainability scale, see Section 4.2.2.2).

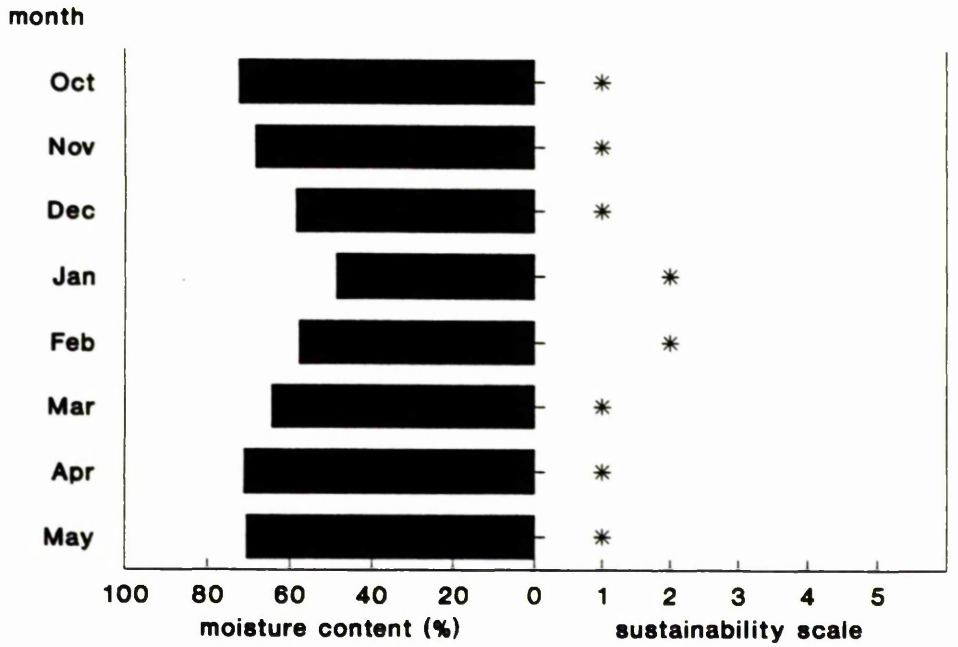


Figure 5.11b. Sustainability of non-grass ground cover species in relation to moisture content, *Dipterocarpus* 1 stand, October 1987 - May 1988. (For sustainability scale, see Section 4.2.2.2).

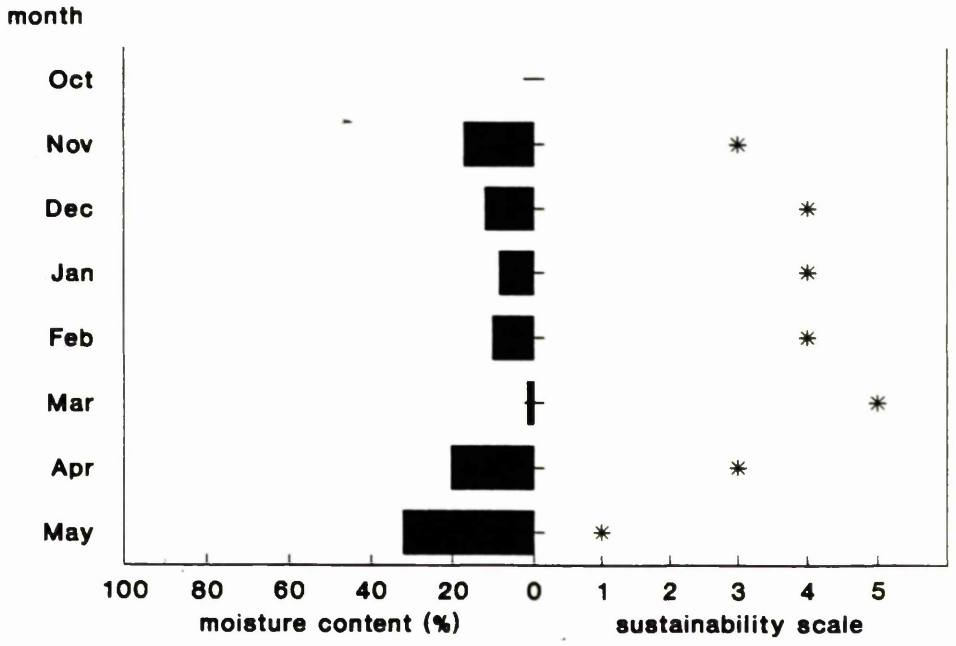


Figure 5.11c. Sustainability of leaf litter in relation to moisture content, *Dipterocarpus* 1 stand, October 1987 - May 1988. (For sustainability scale, see Section 4.2.2.2).

with the lowest value of 1.5% at the end of March. Thus a trend to increased sustainability can clearly be seen, as moisture content decreases in leaf litter. Nevertheless, the maximum moisture content in leaf litter for sustainability beyond flame point is not known, although it sustains at scale point 3 by 20% moisture content. Critical values for sustainability from 10-14 cm, or over half a leaf length (scale point 4), and over 15 cm or over 3/4 (scale point 5), are between 13-16%, and somewhere below 8.4% respectively.

The generally lower critical values of moisture content for leaf litter than for grasses and non-grass ground cover are probably partly due to sampling methods. Unlike leaf litter, the leaf in ground cover was not the only major part of the plant measured for moisture content. The values for grasses and non-grass species were taken from 1 m^2 samples of all the above-ground parts of plants which also consisted of various species. Moreover, the moisture content of individual leaf litter is likely to be more consistent than those of drying, but not yet, shed leaves.

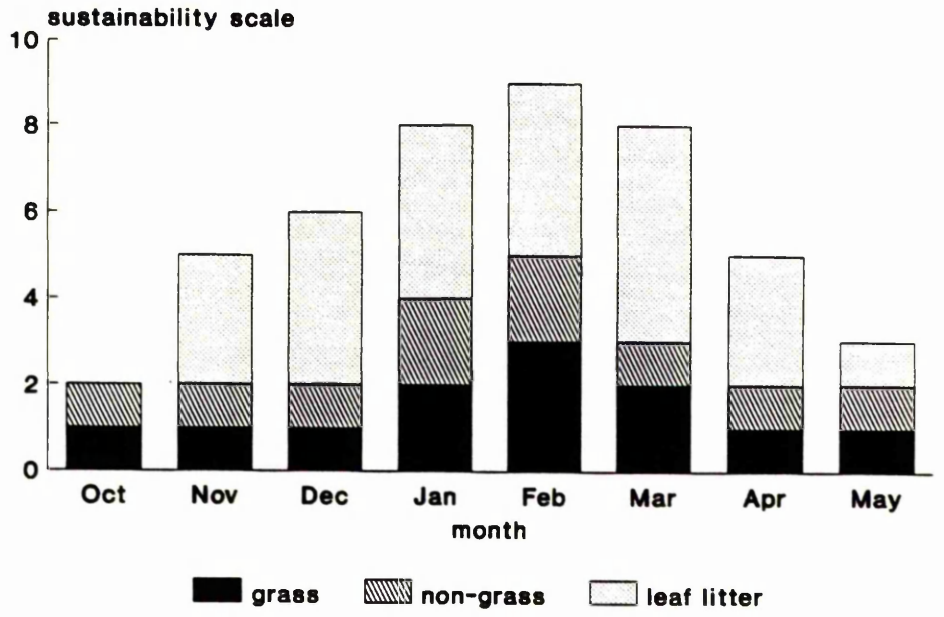


Figure 5.12. Total sustainability of ground fuel in *Dipterocarpus* 1 stand, October 1987 - May 1988.

In the study year, the sustainability of the non-grass ground cover peaked during January and February, when its moisture content was lowest at 49% in the former month (Fig. 5.11b). Grasses also peaked in February (Fig. 5.11a), but leaf litter, which always sustained flame better than other fuel types at scale point 4 from December through to February, burned best at scale point 5 in March (Fig. 5.11c). Overall, however, in terms of their collective internal moisture content, February should be considered the month when fuels are best fitted to sustain a flame (Fig.5.12).

5.5 Discussion

In all the dry dipterocarp forest formations at all the altitudes observed, fire occurred most frequently and extensively in March. In the *Dipterocarpus* 1 association, the month coincided with the time of highest leaf litter fall (>400 g m^{-2}) with lowest moisture content (1.5%) which exhibited the highest sustainability for a burn (scale point 5). This produced a good mean leaf litter cover of 95% at 5 leaves deep. On top of this, March also coincided with the onset of the 'kite wind',

which blew stronger than at any other time of the year, up to 5 knots. It was also the hottest and the least humid month, with a mean temperature of 27° C in the shade and a minimum relative humidity of 33%.

No fire was seen to burn in any *Dipterocarpus* associations around the research station in earlier months. This implies that either no one lit a fire or that the conditions for a burn were somewhat unfavourable, or both. Results of trial burns to test forest sustainability will be discussed in the next chapter to evaluate the possibility of earlier burns if some one were to light a fire. However, under the assumption that the conditions for a burn were less than optimal, the explanation for the absence of fire occurrence prior to March must then lie in the development of climatic and phenological or other biological patterns over the dry season.

If Mather's (1978a) guidelines that forest fires generally start to burn when the air temperature reaches 24°C and relative air humidity drops below 50% is considered, then neither temperature nor relative humidity were important checking factors for burns in February 1988, with a mean temperature of 25°C in the shade and a minimum relative humidity of 41%. Temperature may, however, have played a part in December 1987 and January 1988, when mean values were as low as 17°C and 21°C respectively. It appears that the unusually high rainfall in November and February was a more significant climatic variable. This influences soil and ground cover moisture content, which reached their lowest in January and February. Yet, in itself, the moisture content of ground cover in the *Dipterocarpus* 1 stand was never nearly low enough to sustain fire effectively, although grasses became comparatively drier and burned better than non-grass species. So, despite the lowest ground cover moisture content, in the *Dipterocarpus* association, no fire burned during these two months, while leaf litter moisture content was still over 8%. And, even though by February, leaf litter accumulation was clearly significant at 85% cover and 3 leaves depth, it was far less than the values for March (95% cover, 5 leaves deep), when the moisture content of the ground cover was actually on the increase. It thus seems that leaf litter is the most important source of fuel in terms of the sustainability of burns where the ground cover is only partially dry.

The lowest moisture content of the leaf litter (in March, at 1.5%) occurred one month after the period of thinnest canopy cover in February, which had allowed direct sunlight to dry up the leaves shed on the forest floor. The rest of the old leaves then fell in March, while new leaves were flushing, making March the month of highest leaf litter fall,

but with a greater canopy cover value than in February.

Openness of canopy is also important in the preparation of ground fuel elsewhere, as appears to be the case for the more open *Shorea* association, which began to burn as early as January. Not only is the fuel likely to dry earlier in the season, but here, in comparison to the *Dipterocarpus* 1 association, grasses tend to constitute a far more significant element of the ground cover than do non-grass species. And since there is a greater proportion of dead biomass in grasses than the non-grasses, making the former the drier fuel type of the two, it indicates that an area with a high grass ratio has a higher potential for a burn.

Although no data on the development of conditions for a burn were collected in the *Shorea* association to back up the above observations, records of fire events showed early January burns to occur in open *Shorea* associations with a 20-30% canopy cover, along the road sides below 460 m.a.s.l. Burns in a similar formation at 460 m.a.s.l. around the research station did not occur until almost two months later, but this is because there are fewer people passing through the station area. The potential for earlier burns in the *Shorea* association at 460 m.a.s.l. will be discussed in Chapter 6 when experiments on forest sustainability are considered.

Whether the key fuel was grass or leaf litter, or both, more fires burned in March in all dry dipterocarp forest associations than in any other months. It is thus concluded that March is the time when all the factors combine to create the optimum conditions for burns.

CHAPTER 6.

EXPERIMENTAL RESULTS II: fire behaviour

6.1 Introduction

This chapter is divided into two main Sections. The first looks at the sustainability of all the burns, and the second analyses some characteristics of fire behaviour. However, only the fire behaviour in the burns on the *Dipterocarpus* 1 stand were fully described. Therefore the results presented on Table 6.2 are confined to the common measurements taken in most burns, namely the measurements of maximum temperature and duration of maximum temperature at ground-level, and the mean speed of spread. The spatial pattern of temperatures, the detailed study of the rate and pattern of fire spread, and the sequence of flame height in the *Dipterocarpus* 1 burns will be considered seperately.

The general variables recorded in all test burns are given in Table 6.1. Two main types of data were collected, namely, numerical data (except for dates which are treated as integers), and categorical data, being either nominal or ordinal data. The Apple-McIntosh software programme, 'Statview 512+', was used for the analysis and to measure correlations for the numerical data, employing Pearson's product moment correlation coefficient. For the categorical data, tests for significant relationships on a 2 x 2 contingency table were calculated manually, using Fisher's exact probability test, based on the equation:

$$p = \frac{(A+B)!(C+D)!(A+C)!(B+D)!}{N!A!B!C!D!},$$

where the 2 x 2 contingency table was as following:

	Category I	Category II	Totals
Sample 1	A	B	A+B
Sample 2	C	D	C+D
Totals	A+C	B+D	N

This test was preferred to the Chi-Square test, because it is more suitable for small sample numbers, where expected values in some categories are less than 5, which is the case in this present study. For example, maximum temperature (°C) at ground-level yielded by two categories of grass fuel arrangement may be presented as:

	Fallen	Standing	Totals
≥700° C	4	0	4
<700° C	2	10	12
Totals	6	10	16

,

where 'fallen grass' categorizes burns on grasses with ≥ 50% of grass stalks collapsed, and 'standing grass' categorizes those with <50% collapsed. Probability for the significance of this pattern is calculated as:

$$p = \frac{4!12!6!10!}{16!4!0!2!10!}$$

$$= \frac{12!6!}{16!2!}$$

$$= \frac{(12x11x10x9x8x7x6x5x4x3x2x1)(6x5x4x3x2x1)}{(16x15x14x13x12x11x10x9x8x7x6x5x4x3x2x1)(2x1)}$$

$$= 0.008$$

The level of significance in this study is taken at 0.05 or below. The result of the above example indicates that the chances of this association to be untrue are small enough to accept, with good confidence, that there is a significant difference between temperature yielded from burns on the two different categories of grass arrangement.

6.2 Burn Sustainability

Burn sustainability was measured by means of a simple three-point scale, where '0' means the fire can be ignited, but cannot be sustained at all; '1' means the fire is barely sustained, but can be kept going for a limited period, sometimes long enough for a reasonable measurement of maximum temperature duration to be taken; and '2' means the sustainability of the burn is not inhibited.

As would be expected, good sustainability (scale point 2) produces a high maximum temperature both in ground cover burns and leaf litter burns. When well-sustained, the mean maximum temperature reaches 560° C (range = 252-888°C) for ground cover burns, and 646°C (range = 530-739° C) for leaf litter burns. On the other hand, the mean maximum

Table 6.1. Table of experimental burns and some key variables.

Burn No.	Date	Ignited fuel or on which burn is measured	Ignition time	Site	Altitude (m)	Wind ($m\ s^{-1}$)
5a	19/1/88	*A.mutica*	13.44	Dp.1	c.460	none
5b	19/1/88	*D.tuberculatus* leaf	13.49	Dp.1	c.460	none
7	19/1/88	*D.tuberculatus* leaf	14.00	Dp.1	c.460	none
6a	26/1/88	*D.tuberculatus* leaf	14.23	Dp.1	c.460	none
6b	26/1/88	*A.mutica*	14.28	Dp.1	c.460	none
14a	27/1/88	*A.mutica*	15.20	Dp.2	c.460	none
8	28/1/88	*D.tuberculatus* leaf	13.06	Dp.1	c.460	none
9a	28/1/88	*D.tuberculatus* leaf	13.18	Dp.1	c.460	none
9b	28/1/88	*D.tuberculatus* leaf	13.20	Dp.1	c.460	none
10	28/1/88	*A.mutica*	13.38	Dp.1	c.460	none
11	28/1/88	*S.lithosperma*	13.24	Dp.2	c.460	none
1	29/1/88	*H.triticeus*	13.51	Sh.2	c.270	0.35
2a	29/1/88	*H.triticeus*	10.01	Sh.3	c.210	none
2b	29/1/88	*H.triticeus*	10.15	Sh.3	c.210	none
3	29/1/88	*H.triticeus*	10.59	Sh.4	c.210	none
4	29/1/88	*C.orientalis*	12.48	Sh.5	c.230	none
12	31/1/88	*H.triticeus*	10.22	Sh.1	c.460	none
13	2/2/88	*A.mutica*	13.24	Dp.1	c.460	none
14b	2/2/88	*H.triticeus*	13.44	Dp.2	c.460	none
A	24/2/88	*H.triticeus*	13.56	Dp.1	c.460	none
15	28/2/88	*H.triticeus*	11.08	Sh.1	c.460	0.30
16	23/3/88	*H.triticeus*	13.37	Sh.1	c.460	none
D	25/3/88	*A.mutica*	13.36	Dp.1	c.460	none
17	27/3/88	*A.mutica*	13.48	Dp.1	c.460	none
18	29/3/88	*A.mutica*	15.40	Sh.1	c.460	none
19	19/1/89	*Shorea* leaf	11.03	Lit.1	c.460	none
20	19/1/89	*Shorea* leaf	11.07	Lit.1	c.460	none
21	19/1/89	*Shorea* leaf	11.11	Lit.1	c.460	none
22	19/1/89	*Shorea* leaf	11.22	Lit.1	c.460	none
23	19/1/89	*Shorea* leaf	11.40	Lit.1	c.460	none
24	19/1/89	*Shorea* leaf	13.09	Lit.2	c.460	none
25	19/1/89	*Shorea* leaf	13.22	Lit.2	c.460	none
26	19/1/89	*Shorea* leaf	13.37	Lit.2	c.460	none
27	19/1/89	*Shorea* leaf	13.58	Lit.2	c.460	none
28	19/1/89	*Shorea* leaf	14.13	Lit.2	c.460	none
29	19/1/89	*Shorea* leaf	14.29	Lit.2	c.460	none

continue:

Note

A.mutica = *Apluda mutica* L.

C.orientalis = *Chrysopogon orientalis* A.Camus.

D.tuberculatus = *Dipterocarpus tuberculatus* Roxb.

H.triticeus = *Heteropogon triticeus* Beauv.

S.lithosperma = *Scleria lithosperma* (L.) Sw.

Shorea leaf = leaves of *S.obtusa* Wall. and *S.siamensis* Miq.

Dp. = *Dipterocarpus* association

Sh. = *Shorea* association

Lit. = site of leaf litter burn

Table 6.1. continued

Burn No.	Sky	Air temp (°C)	Canopy cover (%)	Ground cover (%)	Grass ratio (%)	Ground cover height (cm)	Ground cover density (scale)	Grass arrangement (% fallen)
5a	sunny	42	40	80	-	-	3.2-3.3	0
5b	sunny	42	40	80	-	-	3.2-3.3	0
7	sunny	40	40	80	80	125	3.2-3.3	0
6a	sunny	35	40	80	-	-	3.2-3.3	0
6b	sunny	38	40	80	-	-	3.2-3.3	0
14a	sunny	40	20	70	70	130	3.2-3.3	0
8	sunny	44	40	85	60	200	3.2-3.3	0
9a	sunny	39	40	85	70	200	5.4-5.5	0
9b	sunny	39	40	85	70	200	5.4-5.5	0
10	sunny	35	40	80	60	200	3.2-3.3	0
11	sunny	40	10	90	100	22	3.2-3.3	90
1	sunny	48	15	80-90	90	73	5.4-5.5	70
2a	sunny	46	60	50-70	80	100	3.2-3.3	10
2b	sunny	47	60	50-70	80	100	3.2-3.3	10
3	sunny	42	20	80-100	90	65	5.4-5.5	90
4	sunny	37	10	90-100	90	85	3.2-3.3	45° slanting
12	sunny	41	20	90	90	75	5.4-5.5	50
13	sunny	40	40	80	80	150	4.3-4.4	0
14b	sunny	50	15	70	70	25	3.2-3.3	90
A	sunny	36	15	85	60	95	5.4-5.5	10
15	sunny	46	20	95	100	30	5.4-5.5	100
16	sunny	52	20	80	70	70	5.4-5.5	90
D	cloudy	37	40	80	50	55	3.2-3.3	10
17	sunny	38	30	80	60	70	3.2-3.3	10
18	cloudy	39	25	95	90	95	5.4-5.5	20
19	sunny	38	0	-	-	-	-	-
20	sunny	35	0	-	-	-	-	-
21	sunny	38	0	-	-	-	-	-
22	sunny	35	0	-	-	-	-	-
23	sunny	30	0	-	-	-	-	-
24	sunny	53	0	-	-	-	-	-
25	cloudy	31	0	-	-	-	-	-
26	sunny	44	0	-	-	-	-	-
27	sunny	50	0	-	-	-	-	-
28	cloudy	20	0	-	-	-	-	-
29	sunny	32	0	-	-	-	-	-

continue:

Note

For ground cover density scale, see Section 4.2.2.5

Table 6.1. continued

Burn No.	Grass moisture content (%)	Litter moisture content (%)	Litter cover (%)	Litter depth	Head or back fire	Remark
5a	44.2	12.6	50	1	head	not sustain
5b	44.2	12.6	50	1	head	not sustain
7	36.2	8.4	80	3	head	only litter burned
6a	38.8	9.2	50	1	head	not sustain
6b	38.8	9.2	50	1	head	not sustain
14a	38.2	-	-	-	head	not sustain
8	38.6	8.4	60	1	head	not sustain
9a	38.8	8.4	80	2	head	not sustain
9b	38.8	8.4	80	2	head	not sustain
10	36.2	8.4	80	4	head	self-extinguished
11	27.6	-	20	1	head	
1	23.9	3.9	50	2	head	
2a	28.0	6.9	90	5	head	danger, fire put out
2b	28.0	6.9	90	5	head	
3	36.0	-	50	2	head	
4	38.3	-	0	0	haed	danger, fire put out
12	44.7	4.3	65	3	head	
13	36.2	8.4	60	2	head	self-extinguished
14b	36.5	3.6	80	4	head	danger, fire put out
A	35.6	10.0	90	3	head	
15	17.0	2.5	25	2	back	rained on 26,27/2/88
16	31.2	1.5	90	3	head	danger, ran away
D	42.9	1.5	95	4	back	
17	42.9	1.5	95	5	head	
18	38.8	2.1	90	4	head	
19	-	-	100	2	both	both No.19 & 20 only
20	-	-	100	2	both	burned with head fire
21	-	-	100	4	head	
22	-	-	100	6	head	
23	-	-	100	2	head	burned with head fire
24	-	-	100	2	head	ran out of fuel
25	-	-	100	4	head	ran out of fuel
26	-	-	100	6	head	ran out of fuel
27	-	-	100	2	head	ran out of fuel
28	-	-	100	4	head	ran out of fuel
29	-	-	100	4	head	

Table 6.2. Table of results of experimental burns.

Burn No.	Sustain-ability	Maximum temp. (°C)	Duration of the highest 50°C (s)	Duration of temp. >50°C * (min)	Speed (cm s^{-1})
5a	0	-	-	-	-
5b	1	-	-	-	-
7	2	620	5	(3.10)#	-
6a	1	-	-	-	-
6b	0	-	-	-	-
14a	0	-	-	-	-
8	1	-	-	-	-
9a	1	-	-	-	-
9b	1	-	-	-	-
10	2	441	<5	3.00	0.17
11	2	252	15	3.30	0.52
1	2	739	<5	5.05	1.80
2a	2	664	10	5.35	0.20
2b	2	610	5	3.45	0.77
3	2	888	<5	3.35	1.35
4	2	443	5	(3.20)	0.52
12	2	378	5	5.55	0.83
13	2	424	10	4.40	0.22
14b	2	805	10	(1.45)#	0.55
A	1	273	35	7.20	0.50
15	2	465	35	(5.15)	1.26
16	2	842	5	(1.45)#	2.95
D	1	171	75	6.05	0.77
17	2	485	15	5.15	0.50
18	2	408	5	6.35	0.60
19	1	245	30	2.35	-
20	1	200	5	1.05	-
21	2	530	10	6.25	0.30
22	2	605	5	3.10	0.40
23	1	431	40	1.30	0.18
24	2	685	<5	6.25	0.50
25	2	608	20	3.55	0.88
26	2	739	10	3.50	1.18
27	2	668	5	4.05	1.18
28	2	692	<5	(2.45)	1.67
29	2	670	10	3.30	0.97

* (n) indicates incomplete measurement with the lowest temperature drop recorded as following:

No.7, 102°C, ran out of leaf litter
No.4, 58°C, danger - put out fire
No.14b, 263°C, danger - put out fire
No.15, 60°C, danger - put out fire
No.16, 398°C, danger - put out fire
No.28, 60°C, ran out of fuel

omitted from statistical analysis on duration of temperature above 50°C.

temperatures reached under a poorly-sustained burn (scale point 1) are much lower, at 222°C (range = 171-273°C) for the ground cover burn, and 292° C (range = 200-431° C) for the leaf litter burn.

Similarly, in both fuel types, the duration of maximum temperature is briefer under a well-sustained burn, with a mean period of <10 s (range = <5-35 s and <5-20 s for ground cover burns and leaf litter burns respectively). When fire is poorly-sustained, the mean duration periods lengthen to 55 s (range = 35-75 s) in ground cover burns, and 25 s (range = 5-40 s) in leaf litter burns.

Unlike the measurement of the duration of maximum temperature, a shorter duration of temperature above 50° C tends to occur in poorly-sustained litter burns (mean = 1.43 min; range = 1.05-2.35 min), while the opposite is the case in ground cover burns (mean = 6.42 min; range = 6.05-7.20 min). This inconsistency is likely to be a chance bias derived from the few samples of temperature duration that could be measured successfully in poorly-sustained burns, which were often extinguished well before the temperature measurement was satisfactorily completed.

There is also a distinct relationship between the duration of temperature and burn sustainability, but this will be discussed later in Section 6.3.1, when these patterns are described.

Key variables for good sustainability appear to be fuel moisture content and leaf litter depth. Grass fuel sustains well when moisture content is less than 38% (df=18, p=0.007). With respect to leaf litter in the ground cover burn, the result generally confirms the sustainability test for the intrinsic property of individual leaf litter in Section 5.4, namely that a moisture content of around 9% is marginal for sustaining a good burn (df=14, p=0.009 for good sustainability on moisture content of <9%), but probably only if it burns on more than 1-2 leaves deep, as is the case in burn No.7 (3 leaves deep, moisture content 8.4%). Other burns on leaf litter with the same moisture value, but on less leaf depth, were poorly-sustained (e.g. burns No.8, 9a, 9b).

This pattern is most evident in pure leaf litter burns, where successful sustainability (scale point 2) on >3 leaves deep is significant (df=16, p=0.002). This applies even when moisture content is as low as 1.5%. A burn on such low internal moisture content can, however, be poorly-sustained (scale point 1) under certain adverse circumstances. Most of the sustained litter burns were effected within the same day (19 January 1989), on artificially arranged fuel beds with 100% leaf cover value at different leaf depths. One set was tested in the morning (11.00-11.40 am), and the other in the afternoon (13.00-14.30 pm). Burns on 1-2

Table 6.3. Results of burn sustainability.

RESULTS	GOOD SUSTAINABILITY (scale point 2)					
	Leaf litter burn			Ground cover burn		
	mean	range	count	mean	range	count
Maximum temperature(°C)	646	530-739	9/9	560	252-888	14/14
Duration of maximum temperature (s)	<10	<5-20	9/9	<10	<5-35	14/14
Duration of temperature >50°C (min)	4.16	2.45-6.25	8/9	4.38	3.00-6.35	12/14
Moisture content of leaf litter (%)	2.7	1.5-8.4	9/9	4.6	1.5-8.4	11/14
Leaf litter depth	4	2-6	9/9	3	0-5	14/14

RESULTS	POOR SUSTAINABILITY (scale point 1)					
	Leaf litter burn			Ground cover burn		
	mean	range	count	mean	range	count
Maximum temperature(°C)	292	200-431	3/8	222	171-273	2/5
Duration of maximum temperature (s)	25	5-40	3/8	55	35-75	2/5
Duration of temperature >50°C (min)	1.43	1.05-2.35	3/8	6.42	6.05-7.20	2/5
Moisture content of leaf litter (%)	6.4	1.5-12.6	8/8	8.3	1.5-12.6	4/5
[without back fire burn]				10.6	9.2-12.6	3/4
Leaf litter depth	1.6	1-2	8/8	2	1-4	4/5

leaves deep during the morning session were poorly-sustained (scale point 1), while in the afternoon session, burns on 1-2 leaves deep sustained as well (scale point 2) as burns on 3-4 or 5-6 leaves deep, despite the slightly lower moisture content of the leaf litter sample from the morning session (1.5%) than the afternoon samples (2.1%). As there was an unusually heavy dew that morning, even as late as 11.00 am, under bright sunshine, it is likely that the poor sustainability (scale point 1) could be due to high surface soil moisture content and atmospheric humidity.

The importance of the values for leaf litter cover and canopy cover with respect to burn sustainability is difficult to assess critically here, for experiments on sustained leaf litter burns were mostly on artificially arranged fuel beds of 100% cover value, and under 0% tree canopy. Nevertheless, there appears to be no correlation between either leaf litter cover or canopy cover values and sustainability in the ground cover burn. A further burning experiment, designed specifically to answer this question, is now needed. It is important, particularly for our understanding of the seasonal timing of fire, because the canopy becomes thin as it sheds leaves and this simultaneously allows in more direct sunlight to dry up the accummulated leaf litter on the forest floor.

Finally, it appears that back fires are another factor that can reduce the capacity to sustain fire. For example, plot D was a back fire, and it was poorly-sustained, even though the moisture content of the leaf litter was only 1.5%. It was also noted that the poorly-sustained leaf litter burns, No.19 and No.20, in the morning session, which were burned under both head and back fires, sustained comparatively better under the head fires. The back fire was extremely weak or easily extinguished.

6.3 Characteristics of fire behaviour

This Section looks at the following characteristics of fire behaviour, namely: maximum temperature and the duration of maximum temperature; the spatial pattern of temperatures;, the rate and pattern of fire spread; and the temporal pattern of flame height and frontal fireline intensity.

6.3.1 Maximum temperature and the duration of maximum temperature

Maximum temperature and the duration of maximum temperature were measured with a non-contact, infra-red pyrometer, set at an emissivity of 0.9, with temperature readings taken manually at every 5 s

Table 6.4. Duration of temperature: types of curve patterns.

TEMPERATURE RISE	TEMPERATURE PATTERN AT THE MEASURING POINT						TEMPERATURE DROP
	Level-top peak		Single sharp high peak		Few seperate sharp high peaks		
No preheating (sudden temperature rise) ↑	19, (23)		(20) 22,24 26	2a,3			Sudden drop ↓
			21	2b,4 (14) (16)		11	Sudden,with small peak or peaks ↘
		D				A	Long gradual drop ↘
			25,27 28,29				staggered drop ↘
						17	Steady drop ↘
Staggered rise				7,10			Sudden,with small peak or peaks ↘
				13			Steady drop ↘
Seperate preheating peak or peaks				1		12	Sudden drop ↓
		15				18	Sudden,with small peak or peaks ↘
	Lit	Grd	Lit	Grd	Lit	Grd	
FUEL TYPES							

(n) = burn with disrupted measurement

Lit = leaf litter burn

Grd = ground cover burn

(see Section 4.2.1.1). The measurements were made at fixed points, as shown in Fig.4.1.

6.3.1.1 Types of pattern of temperature duration

Table 6.4 sums up the major temperature duration patterns that occurred in the test burns, where three main temperature curves were apparent. The most common was where temperature rises and drops abruptly when the fire reaches the measuring point, forming a graph of one single sharp high peak (Fig.6.1a). The other curve types consisted of a few seperate sharp high peaks (Fig.5.1b), or a more or less level-top peak, resembling a high plateau (Fig.5.1c). The latter two types, and in particular the level-top temperature peak, tend to have a longer duration of maximum temperature (see Table 6.5).

Temperature rise is usually very sudden, and there is no preheating in most burns, although a few small peaks prior to the main measuring point may occur in some examples (see Table 6.4). Temperature drop is also usually sudden, sometimes followed by one or two small peaks, with the exception of most burns in the *Dipterocarpus* 1 stand (e.g. No.13,

	SINGLE HIGH PEAK					
	Leaf litter burn			Ground cover burn		
	mean	range	count	mean	range	count
Maximum temperature (°C)	602	200-739	10	651	424-888	9
Duration of maximum temperature (s)	<10	<5-20	10	5	<5-10	9
Duration of temperature >50°C (min)	3.54	1.05-6.25	9	4.09	3.00-5.35	7
Head fire			9/10			9/9
Back fire			1/10			0/9
Good sustainability			9/10			9/9
Poor sustainability			1/10			0/9

Table 6.5a. Results of burns with single high peak curve.

Table 6.5b. Results of burns with few seperate high peaks.

	FEW SEPERATE HIGH PEAKS		
	Ground cover burn		
	mean	range	count
Maximum temperature (°C)	359	252-485	5
Duration of maximum temperature (s)	15	5-35	5
Duration of temperature >50°C (min)	5.43	3.30-7.20	5
Head fire			5/5
Back fire			0/5
Good sustainability			4/5
Poor sustainability			1/5

17, in particular A and D), where the temperature drops tended to be a longer and more gradual process.

In both ground cover and litter burns, the single high peak pattern, especially ones with a sudden temperature rise and drop, tends to be associated with a high maximum temperature, with a mean of 625°C (range = 200-888°C); a short duration of maximum temperature, with a mean of $\geq$5 s (range = <5-10 s); and good sustainability (scale point 1, compare Fig.6.2a to Fig.6.2b). No sudden temperature drop occurred in any burn on *Apluda mutica*, a grass species that remained largely standing and which was never completely burned throughout the study. There was also the tendency for preheating to occur where the leaf litter cover percentage was low (often <80%), or when the ground cover gets very dense in places, or if its height is above 150 to 200 cm, which suggests grasses in a standing position. All these factors perhaps indicate that the more uniform the fuel distribution and the better the burn combusts, then the briefer and smoother will be the temperature duration pattern. It further seems that the level-top peak duration pattern might be a characteristic of back fire burns, where it is associated with low maximum temperatures

RESULTS	LEVEL-TOP PEAK					
	Leaf litter burn			Ground cover burn		
	mean	range	count	mean	range	count
Maximum temperature (°C)	338	245-431	2	318	171-465	2
Duration of maximum temperature (s)	35	30-40	2	55	35-75	2
Duration of temperature >50°C (min)	2.03	1.30-2.35	2	5.40	5.15-6.05	2
Head fire			1/2			0/2
Back fire			1/2			2/2
Good sustainability			0/2			1/2
Poor sustainability			0/2			1/2

Table 6.5c. Results of burns with a level-top peak.

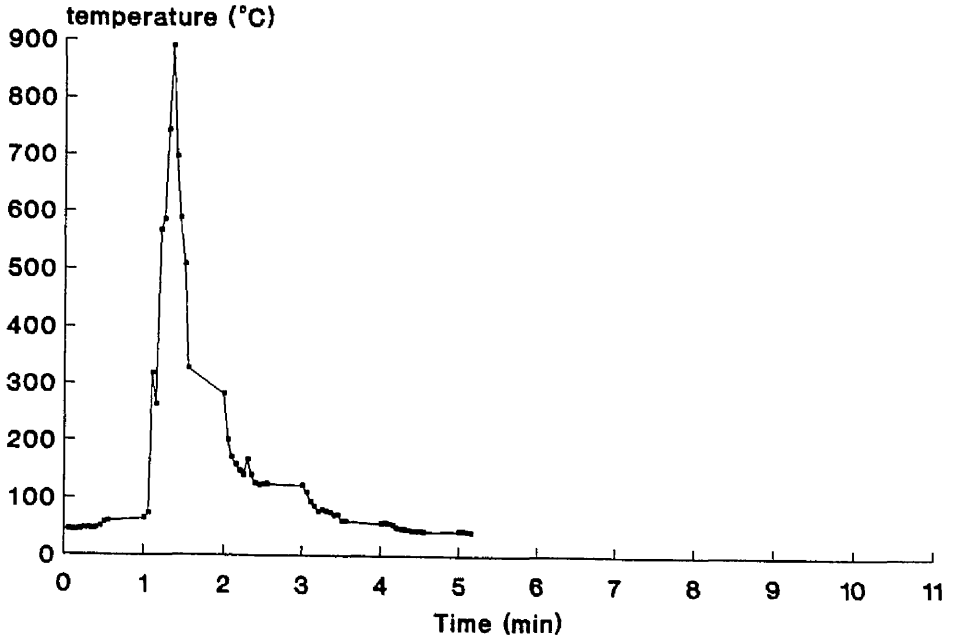


Figure 6.1a. Typical duration of temperature pattern in a well-sustained head fire (single sharp peak). This is a burn on ground cover (fallen *Heteropogon triticeus*).

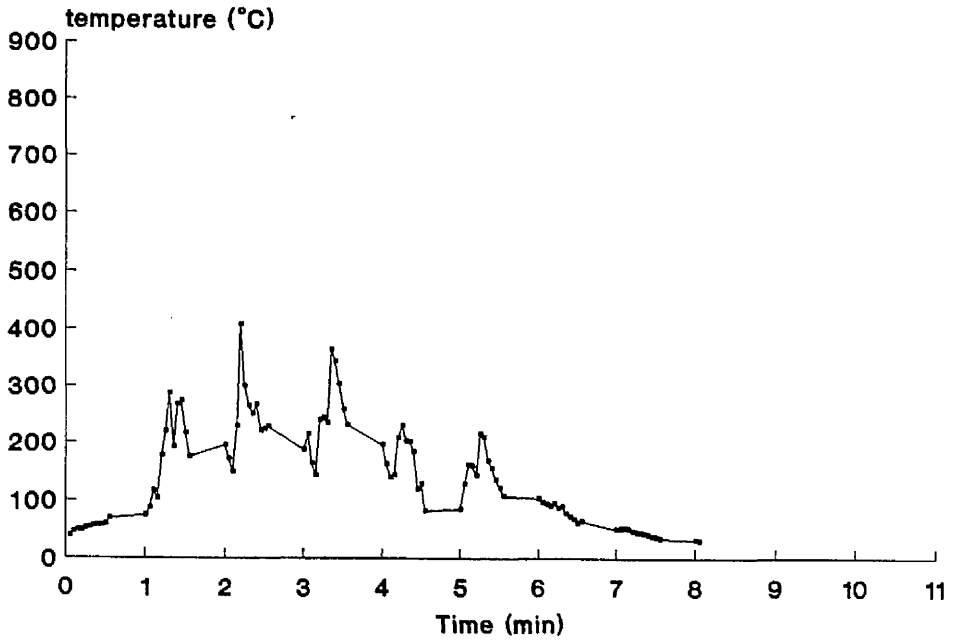


Figure 6.1b. Typical duration of temperature pattern in a burn on standing grass and in some poorly-sustained burns (few or several sharp peaks). This is on standing *Apluda mutica*.

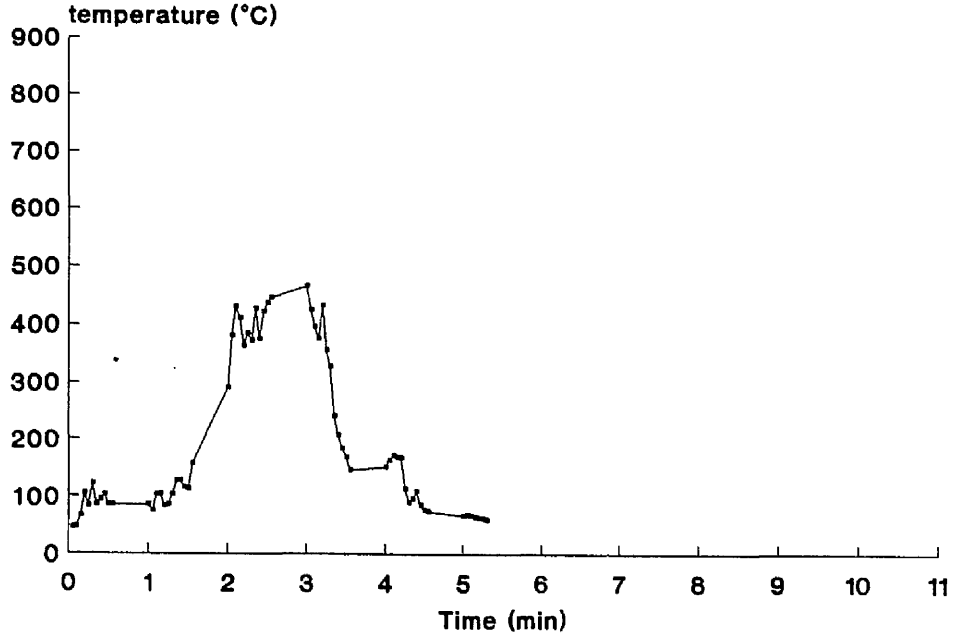


Figure 6.1c. Typical duration of temperature pattern in a back fire burn and in some poorly-sustained burns. This is a back fire burn on fallen *Heteropogon triticeus*.

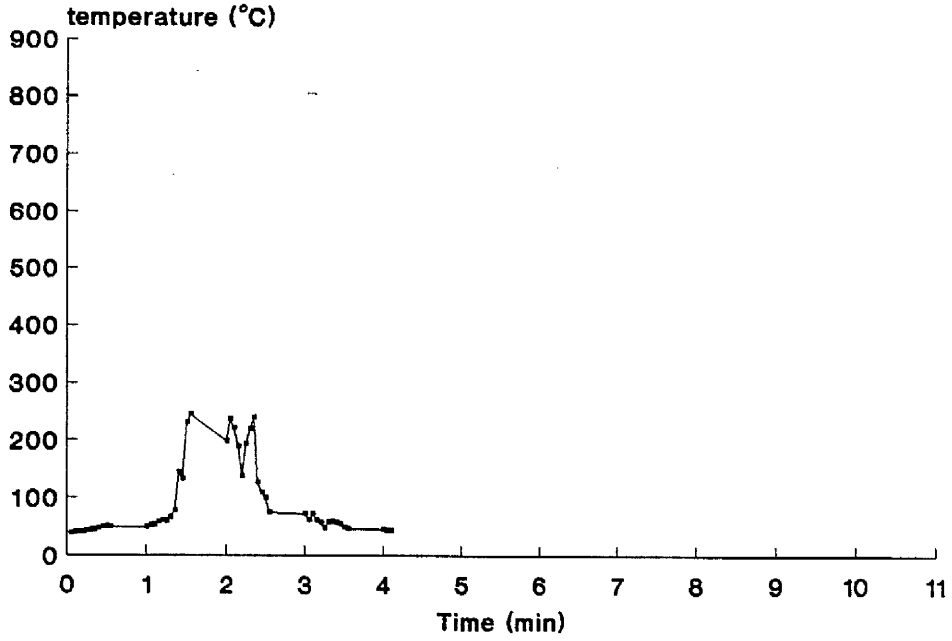


Figure 6.2a. Typical duration of temperature pattern on a poorly-sustained leaf litter burn.

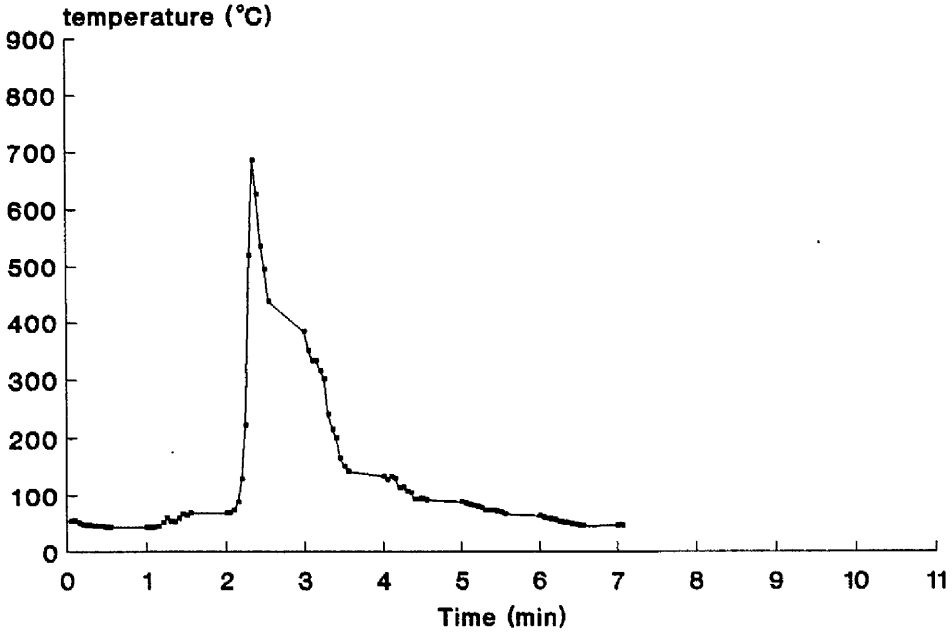


Figure 6.2b. Typical duration of temperature pattern on a well-sustained leaf litter burn under a head fire.

with a mean of around 300° C in this present study (range = 171-465° C).

6.3.1.2 The maximum temperature at ground-level

The higher the maximum temperature attained in both leaf litter and ground cover burns, the faster the mean speed of the fire spread. Figs 6.3a and b show fairly clear regressions of these correlations (ground cover burn, df=15, r^2=0.571, r=0.532, p=0.03; litter burn, df=8, r^2=0.559, r=0.748, p=0.02). Furthermore, a short duration of maximum temperature tends to be associated with a high maximum temperature, although the correlation is significant only for ground cover burns (df=15, r^2=0.339, r=-0.582, p=0.02; Fig.6.4).

Three variables significantly influence maximum temperature in ground cover burns. These are air temperature, the grass species burned, and their arrangement as fuel. The regression in Fig.6.5 shows clearly how higher air temperatures tend to be associated with higher fire temperatures (df=15, r^2=0.571, r=0.755, p=0.001). Likewise, the arrangement of the burned grasses proves to be equally important, with fallen grasses (≥50% collapsed stalks), as opposed to an upright arrangement, giving a higher temperature, with a mean of 665°C (range = 252-888°C), while the mean temperature for standing grass (<50% collapsed stalks) is 430° C (range = 171-664°C; df=15, p=0.008 for fallen grass yeilding >700° C). The differences are even more marked when only the major grass species studied of comparable biomass are taken into account, namely *Heteropogon triticeus* and *Apluda mutica*. Here, the mean maximum temperature for fallen grass becomes as high as 748°C (range = 465-888°C).

Moisture content, on the other hand, appears to be insignificant. It thus seems that the internal properties of the fuel, such as moisture content, are only directly important to some extent when a burn is not yet well-sustained. Once this level is reached, however, this variable becomes secondary, and its importance is overtaken by certain external factors, such as air temperature and fuel arrangement. The latter varies with the species involved. Of the grasses, only the stalks of *Heteropogon triticeus* and *Eulalia bicornuta* collapsed in the dry season, while the stalks of *Chrysopogon orientalis* slanted at a 45° angle, and *Apluda mutica* always remained mostly upright. These different characteristics are probably determined by different cellular structures, such as the silica content of each grass species, although moisture content may have an important indirect role to play, as it influences the turgidity within plant cells.

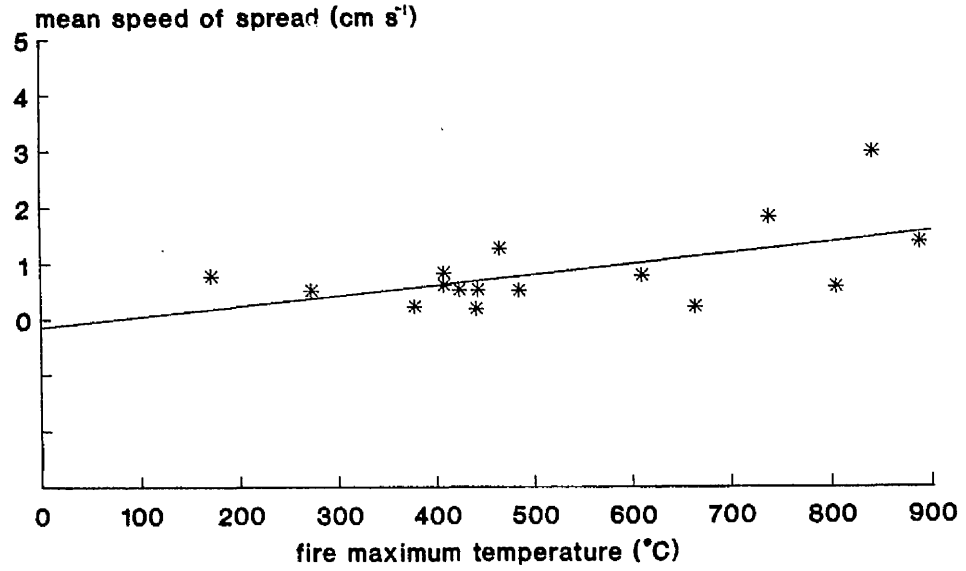


Figure 6.3a. Regression between fire maximum temperature and the rate of fire spread in ground cover burns.

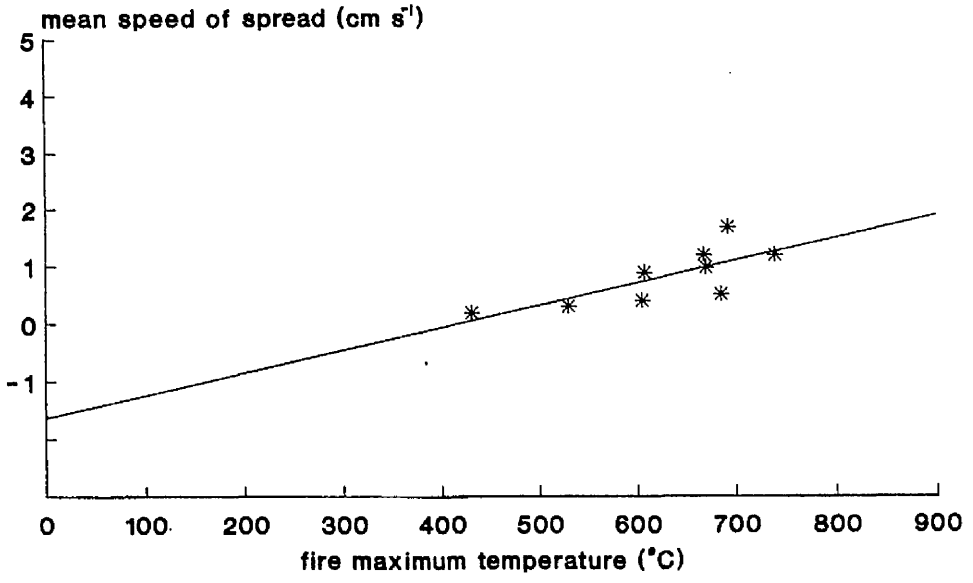


Figure 6.3b. Regression between fire maximum temperature and the rate of fire spread in leaf litter burns.

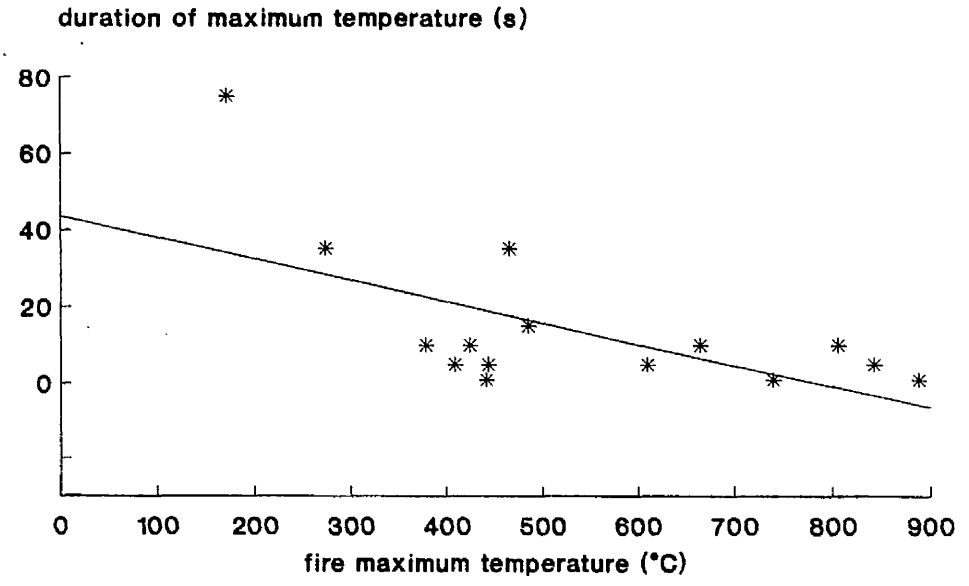


Figure 6.4. Regression between fire maximum temperatures and their duration periods in ground cover burns.

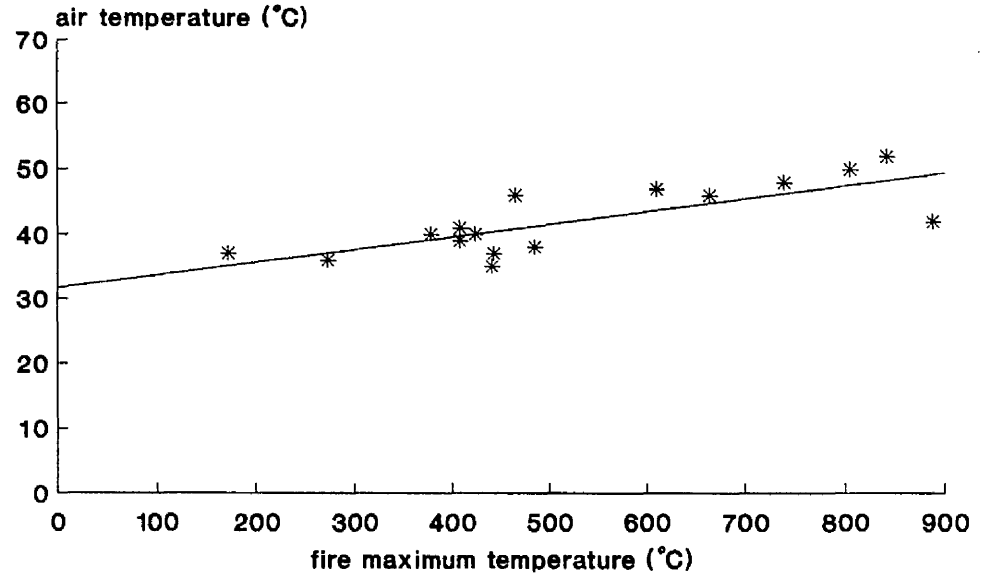


Figure 6.5. Regression between fire maximum temperature and air temperature in ground cover burns.

Table 6.6: Maximum temperature (°C) results.

FUEL TYPES	MEAN	RANGE	COUNT	S	V
Ground cover burn	518	171-888	16	217.6	42
Leaf litter burn	558	200-739	12	176.6	31.7

VARIABLES	MAXIMUM TEMPERATURE (°C)		
	Ground cover burn		
	mean	range	count
Heteropogon triticeus	629	273-888	9/9
Apluda mutica	386	171-485	5/8
Fallen grass (70-100% fallen)	665	252-888	6/6
Fallen grass without No.11*	748	465-888	5/5
Standing grass (0-50% fallen)	430	171-664	10/13
Standing grass without No.4*	428	171-664	9/12

* burn No.11 & No.4 are on non-*A. mutica/H. triticeus*.

It is further probable that head fires and back fires also have a direct influence on maximum temperature, although this cannot be seen clearly here, because of the very few samples of ground cover burned under back fires. It is, however, worth noting the temperature differences between burn D (171°C) and burn No.17 (485°C) on standing *Apluda mutica*, and between burn No.15 (465°C) and No.16 (842°C) on fallen *Heteropogon triticeus*, where each pair has very similar variables, except that D and No.15 were back fires, and No.15 and 16 head fires. The differences of maximum temperature between the head fire burns (higher temperature) and the back fire burns (lower temperature) in both cases were of the order of 400°C. Similar patterns also occurred in leaf litter burns.

Unlike in ground cover burns, however, there is no correlation between air temperature and maximum fire temperature in the leaf litter burns. As previously stressed, most of the sustained leaf litter burns

were done in the same day (19 January 1989), on artificially arranged fuel beds with 100% cover at different leaf depths. It was found that, not only was there a marked difference in the sustainability of burns between the morning (11.00-11.40 am) and the afternoon (13.00-14.30 pm) sessions (see Section 6.2), but also that there is a difference in the maximum fire temperatures in regard to different leaf depths. In the morning session, the burn on 1-2 leaves deep did not sustain well (scale point 1), but the one that did (No.23) attained 400°C, while burns at 3-4 leaves deep (No.21), and 6 leaves deep (No.22), reached 500°C and 600°C respectively. There is, thus, an increase in burn sustainability, as well as an increase in maximum fire temperature, as the leaf depth increases. In the afternoon, however, burns on all leaf depths sustained equally well (scale point 2), and there is hardly any significant differences in their maximum temperatures. Burns on 1-2 leaves deep (No.24, 27), and 3-4 leaves deep (No.25, 28, 29), and even on 6 leaves deep (No.26), all reached a maximum fire temperature of between 600-700°C, or just over. With such different behaviour between the morning and afternoon sessions, no significant correlation between leaf litter depth and maximum temperature is apparent.

To summarize, therefore, the maximum temperatures reached in ground cover burns range from 171-888°C, with a mean of 518°C (S=217.6, V=42). The highest temperatures were all recorded in head fire burns on fallen *Heteropogon triticeus*, ranging from over 700°C to almost 900°C (739-888°C); in contrast, the lowest temperature of 171°C was recorded in a back fire burn on standing *Apluda mutica*. Leaf litter burns presented a similar range, from 200-739°C, with a mean of 558°C (S=176.6, V=31.7), but these never reached higher than the lowest temperature from the head fire burns on fallen *H.triticeus* (739°C).

6.3.1.3 Duration of maximum temperature and duration of temperature above 50°C

As the reading for the duration of temperature was taken manually at 5 s intervals, the period of a given range of temperature duration (i.e. a range of maximum temperature, or a range of temperature above 50°C) is taken from the time between two recorded values that appear within the set range. Thus the value for a duration period should be regarded as the minimum value, except when the relevant value only occurred once in the reading, in which case the duration period is treated as a maximum value, since it can only be noted as '<5 s'.

The duration of the absolute maximum temperature is usually

extremely brief, most being less than 5 s and most possibly lasting around only 1 s. None was more than 10 s, except for the plot D burn under a back fire (40 s). Therefore, the duration of maximum temperature here is taken from the period when a fire sustains the highest 50°C range. And since the thermal death point for most plant tissues is around 60°C (Hare 1961), although it can also vary from between 50-55°C (Baker 1929, after Wright & Bailey 1982), the duration of temperature above 50°C is also counted. This is taken from the time when the temperature first reaches 50°C to the time when it first drops down to 50°C again. Measurement in some burns, however, was not completed, and the temperatures are not recorded to the first 50°C drop. The reasons for this are noted in table 6.2, where the duration of temperatures above 50°C of the incomplete measurements are shown in brackets.

FUEL TYPES	MEAN	RANGE	COUNT	S	V
Ground cover burn	15	<5-75	16	19.3	132.2
Leaf litter burn	<15	<5-40	12	12	102.6

VARIABLES	DURATION OF MAXIMUM TEMPERATURE (s)		
	mean	range	count
Head fire	<10	<5-35	14/17
Back fire	55	35-75	2/2

Table 6.7. Results for duration of maximum temperature measurements of the highest 50°C bracket in ground cover burns (in s).

In ground cover burns, the duration of maximum temperature lasts from <5-10 s on the duration pattern with a single sharp high peak, to from 5-35 s on the ones with a few sharp peaks, and from 35-75 s on the burns with a level-top pattern. Similarly, in leaf litter burns, the duration periods last from <5-20 s for the burns with a single sharp peak, and 30-40 s for level-top burns. No patterns with a few separated peaks were recorded for leaf litter burns. The shortest duration of temperature above 50°C also occurred in a ground cover burn with a single sharp high peak, with a mean of around 4 min (range = 3 min - 5 min 35 s), while the mean duration period of other ground cover burns was around 5

min 40 s (range = 3 min 30 s - 7 min 20 s).

The duration of maximum temperature in ground cover burns further reflects the pattern of temperature drop. As would be expected, the steady, or very gradual drop, gives the longest duration (mean = 35 s; range = 10-75 s), staggered temperature drops or sudden drops with small peaks give a shorter duration (mean = 10 s; range = 5-35 s), and the sudden drop is, of course, the shortest (mean = <5 s; range = <5-10 s).

There do not seem to be many variables which determine directly the duration of maximum temperature, except for sustainability, and whether a head or a back fire. Poor sustainability produces a longer duration in both ground cover burns (mean = 55 s; range = 35-75 s) and leaf litter burns (mean = 25 s; range = 5-40 s), while the mean duration period in a well-sustained burn is <10 s in both fuel types. The same is also very likely to be true for back fires in the ground cover burns, but samples are too few to be certain. Otherwise, no physical condition or fuel characteristic appears to be particularly influential.

FUEL TYPES	MEAN	RANGE	COUNT	S	V
Ground cover burn	4,55	3.00-7.20	14	79.9	27
Leaf litter burn	3,34	1.05-6.25	11	102	47.7

Table 6.8. Results for duration of temperature measurements above 50°C in ground cover burns (in min,S).

A long duration of maximum temperature does not neccessarily give either a long or a short duration of temperature above 50°C. Indeed, hardly any significant correlation with other variables is demonstrated here for the latter. This is probably partly due to the neccessary omission of burns No.14b and No.16 from the statistical analysis. Both are high temperature head fire burns on fallen *Heteropogon triticeus*, where the fire burned dangerously and had to be put out for safety reasons, before the necessary temperature measurements could be completed.

6.3.2 The spatial pattern of temperature

The spatial pattern of temperature was measured on the burns in the *Dipterocarpus* 1 stand. Nine points were sampled in each burn: three of these were tested at every 25 cm interval above ground from the ground-level up to 2 metres, while the remaining six were tested at every

50 cm. Temperature was also measured at 5 cm underground at all points, and pyrometer samples were also placed at different specific locations, such as in a clump of grasses or seedlings, or where the leaf litter was particularly deep. Both plots were mixed ground cover burns with leaf litter, with both dense and thin patches.

As described previously in Section 4.2.1.2, two sets of pyrometers were calibrated in this study. One was over a duration period of 10 s, the other of 30 s. The first were used to interprete head fire temperatures, as in the case of the plot A burn. The other set proved more suitable for the interpretation of back fire temperatures. Since plot D was a partial back fire, the second calibration was selected for the burn. Because the duration of head fires at ground-level in the field is often less than 10 s, and the 'thermocolor' pyrometer only measures to the nearest colour change below the highest temperature, the results produced here should be regarded as minimum values. This applies especially to the burn in plot D, where colour changes in both head and back fires, as well as in a **flanking fire**, are interpreted with the long duration calibration. This inevitably gives some colour changes under the head fire which are probably 25-50° C lower than they ought to be.

Graphic profiles of the spatial pattern of temperature in plots A and D are portrayed in Figs 6.6a & b, which show the mean temperature measured at 5 cm underground, at ground-level, at 25 cm, 50 cm, 100 cm and 150 cm above ground. It is evident that the highest temperatures in both burns occurred at ground-level and at 25 cm above ground. Mean temperature at ground-level was around 300° C in both burns, ranging from 125-550°C in plot A, using the head fire calibration, and from 75-450° C in plot D, using the back fire calibration. Similarly, temperatures at 25 cm above ground ranged from 120-550°C in plot A, and 70-450°C in plot D. At 50 cm above ground, temperature drops to around 75-125°C, with one or two pyrometers remaining unchanged, indicating that both fires were essentially leaf litter burns (Stott 1986). In contrast, Stott (1986) found that a typical ground cover burn would attain the highest temperature at 50 cm above ground, with a mean of around 300° C.

This shows that, in a relatively moist dry dipterocarp forest, such as this *Dipterocarpus* association, there is little difference in the spatial pattern of temperatures between the different seasonal timings of burns, if the grasses are not allowed to dry up completely during the fire season. In this case, the major fuel was leaf litter. The differences in the amount of leaf litter accumulation between the first sustainable fire (plot A, 2-3 leaves deep) and at the end of the dry

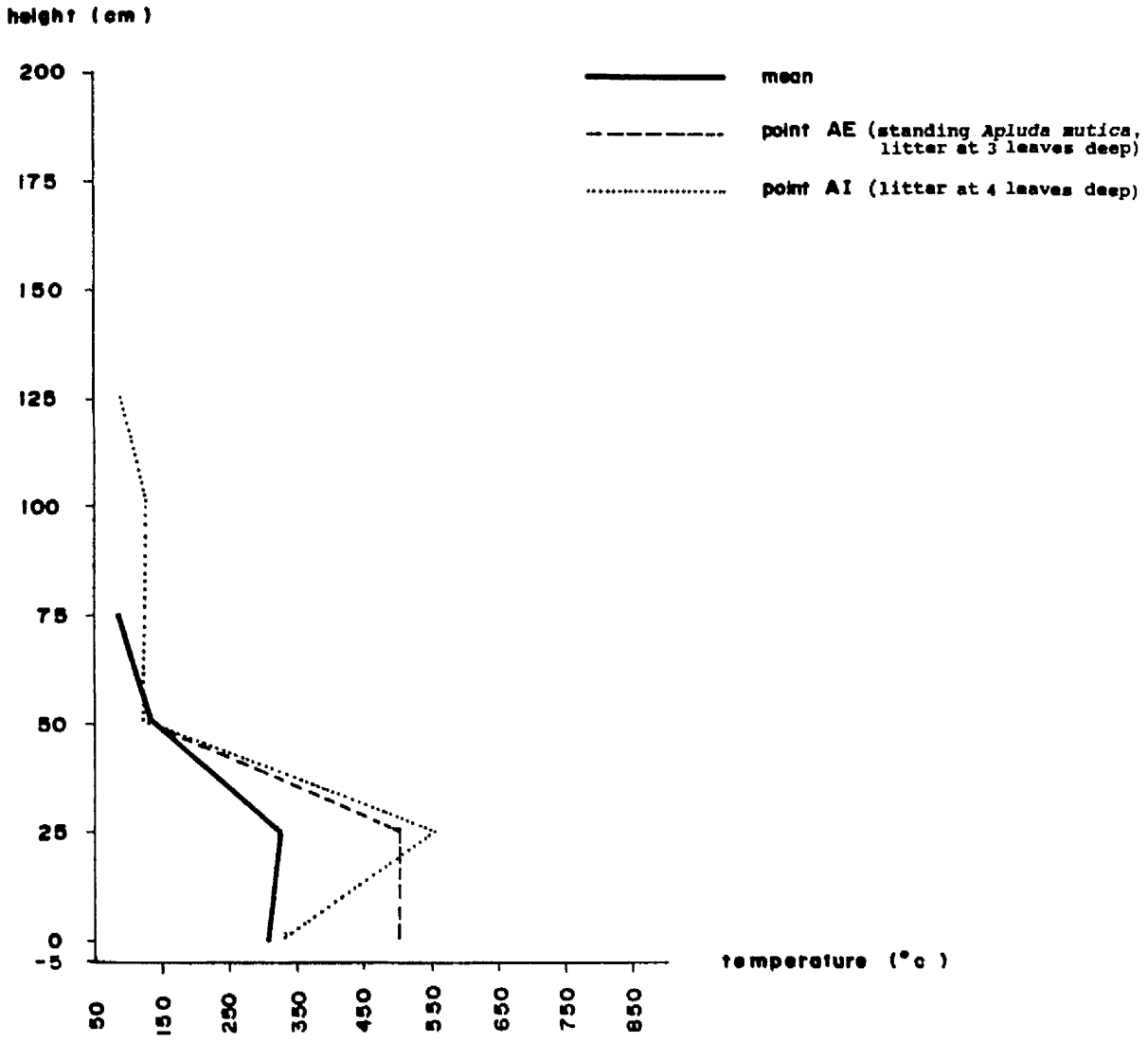


Figure 6.6a. Profile of the vertical pattern of temperature, plot A, (24 February 1988).

season (plot D, 4 leaves deep) was not great enough to produce significant differences in the temperature patterns. In his experiment, Stott (1986) found a burn on 6-7 leaves deep produced a marked difference in temperature profile, where a temperature of 700°C was attained at ground-level. He termed this an 'extreme leaf litter burn'. In this forest stand, leaf litter must be accumulated for over a year, without being burned, to build up to an amount which produces such an 'extreme leaf litter burn' (see Section 7.3.5).

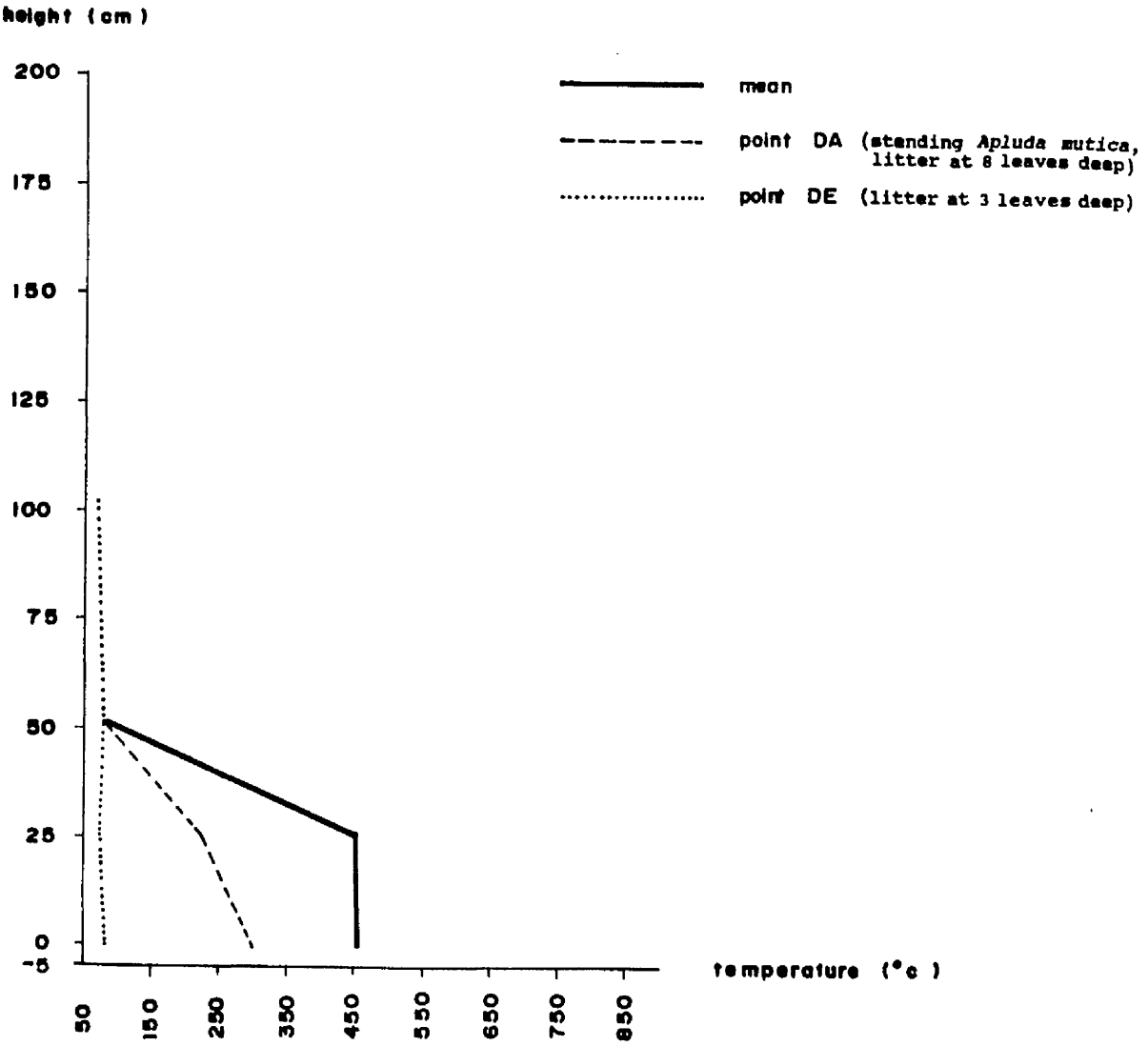


Figure 6.6b. Profile of the vertical pattern of temperature, plot D, (25 March 1988).

Since little correlation was shown with different seasonal timings in the permanent plots of the *Dipterocarpus* 1 stand, it may be worth looking at the differences in fuel type, in order to complement our understanding of fuel characteristics and resultant fire behaviour. Three sampling points, with measurements taken at 5 cm underground, at ground-level, at 25 cm, 50 cm, 100 cm, 150 cm and 200 cm above ground, were placed in four burns in the *Shorea* association throughout the dry season to provide additional data for any qualitative information

concerning fire timing. If all the samples are put together from both the *Shorea* and the *Dipterocarpus* burns, they permit a limited quantitative analysis of the spatial pattern of temperature related to different sources of fuel. Sampling points can be categorized by three major types of fuel, namely: 'grass burn', where grass is the major fuel; 'mixed burn' or 'partial ground cover burn', where the grass cover is thin, and the ground is covered partly with leaf litter, or where there are seedlings, or a composition of seedlings, forbs, herbs and leaf litter; and finally, 'leaf litter burn', where leaf litter is the single source of fuel. Table 6.9 and Figs 6.7a-c give a summary of the temperature profiles for these categories of burns.

The result of the leaf litter burns generally confirm the previous work done by Stott (1986), with the highest temperature occurring at ground-level, with a mean value of around 400°C. As litter samples here are mostly at 3-4 leaves depth, the temperature range of 325-525°C is much less than that obtained by Stott (1986: range = 275-700°C), who experimented with a greater range of leaf depths, a factor which can influence maximum temperature, as suggested in litter burn test, using the infra-red pyrometer. Furthermore, the temperature measured here correlates reasonably with the absolute maximum temperature measured by the infra-red pyrometer (mean *c*.500°C for 3-4 leaf depth in the morning, and *c*.600°C in the afternoon), bearing in mind that the absolute maximum temperature of the leaf litter burn was recorded under a 0% canopy cover, and that the temperature reading from the 'thermocolor' pyrometers must be treated as minimum values.

At 25 cm above the ground, temperatures remained virtually as high as those at ground-level, with a mean around 400°C (range = ≤125-550°C). But, as also seen in Stott (1986), temperature then falls to below 200°C at the 50 cm level, and some pyrometers are left unchanged, indicating a temperature below 75°C for a back fire, and below 125°C for a head fire. This pattern was quite consistent.

The temperature profiles of grass burns, on the other hand, were very inconsistent, with temperatures at ground-level up to 100 cm, both ranging from ≤ 75°C to 750°C, or over. This probably reflects a combination of factors, such as grass arrangement, air temperature at the time of each burn, and the wind effects created once a fire has started. Generally, however, the highest temperature occurred at 25 cm above the ground, with a mean of around 460°C (range = ≤125->750°C). At the 50 cm and 100 cm levels, the mean temperature dropped to >200°C (range = ≤75->750°C), with some pyrometer samples remain unchanged. One sampling

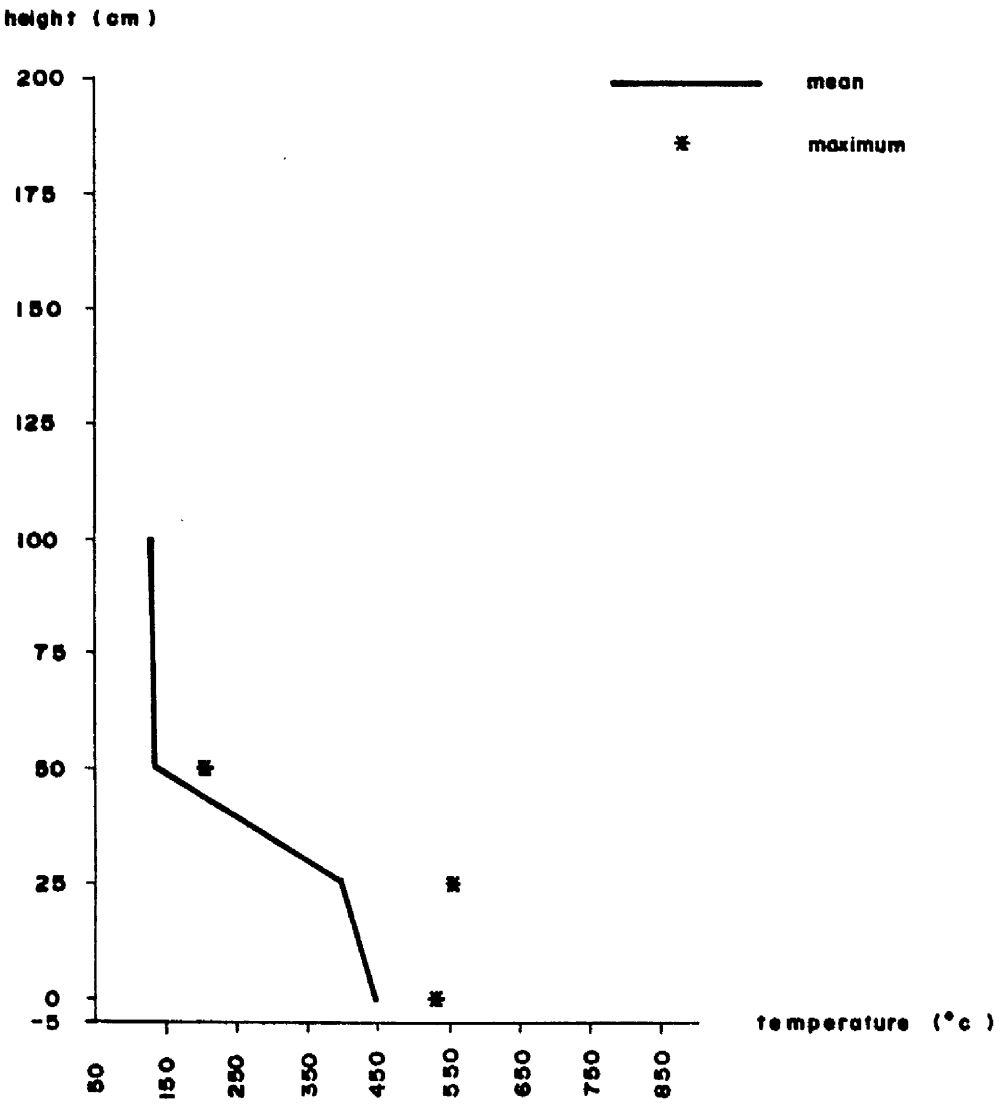


Figure 6.7a. Temperature profile of leaf litter burns.

point, in a head fire burn (No.16), which was placed in the middle of a dense, and fallen, clump of *Heteropogon triticeus*, attained a temperature of over 300°C at 150 cm above the ground and only dropped to 125°C at the 200 cm level. This burn bears the characteristics of the 'extreme ground cover burn' described by Stott (1986), where the ground-level temperature reaches 750°C, and even higher, probably up to 850°C[10] at 25-100 cm above the ground.

[10] This temperature is higher than the calibration of the 'thermocolor' pyrometers (800°C); interestingly there was a colour change in the field. The absolute maximum temperature measured by the infra-red pyrometer in this burn was 842° C at ground level.

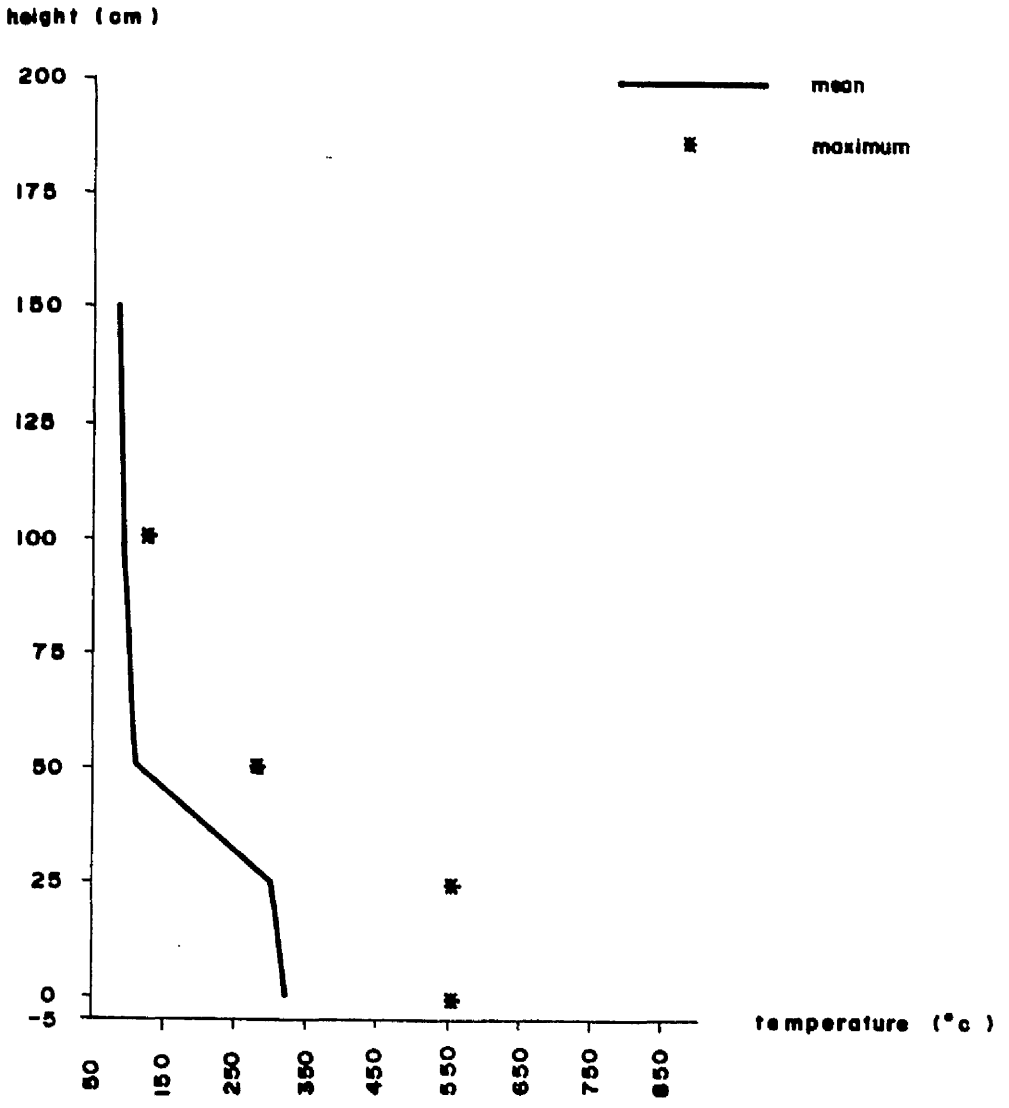


Figure 6.7b. Temperature profile of burns on mixed ground cover with leaf litter.

The mean ground-level temperature of all grass burns in this study was around 300°C (range = 75-750°C), with temperatures occurring on >75% fallen grass (range = 450-750°C) being appreciably higher than those on standing grass (range = 75-325°C; see table 6.10). Temperatures of around ≤125°C on a partially fallen grass arrangement were even lower at this level, but this could well be due to the influence of other unknown factors. At 100 cm above the ground, no pyrometer samples on standing grass changed colour, while on fallen grass, they showed a range of

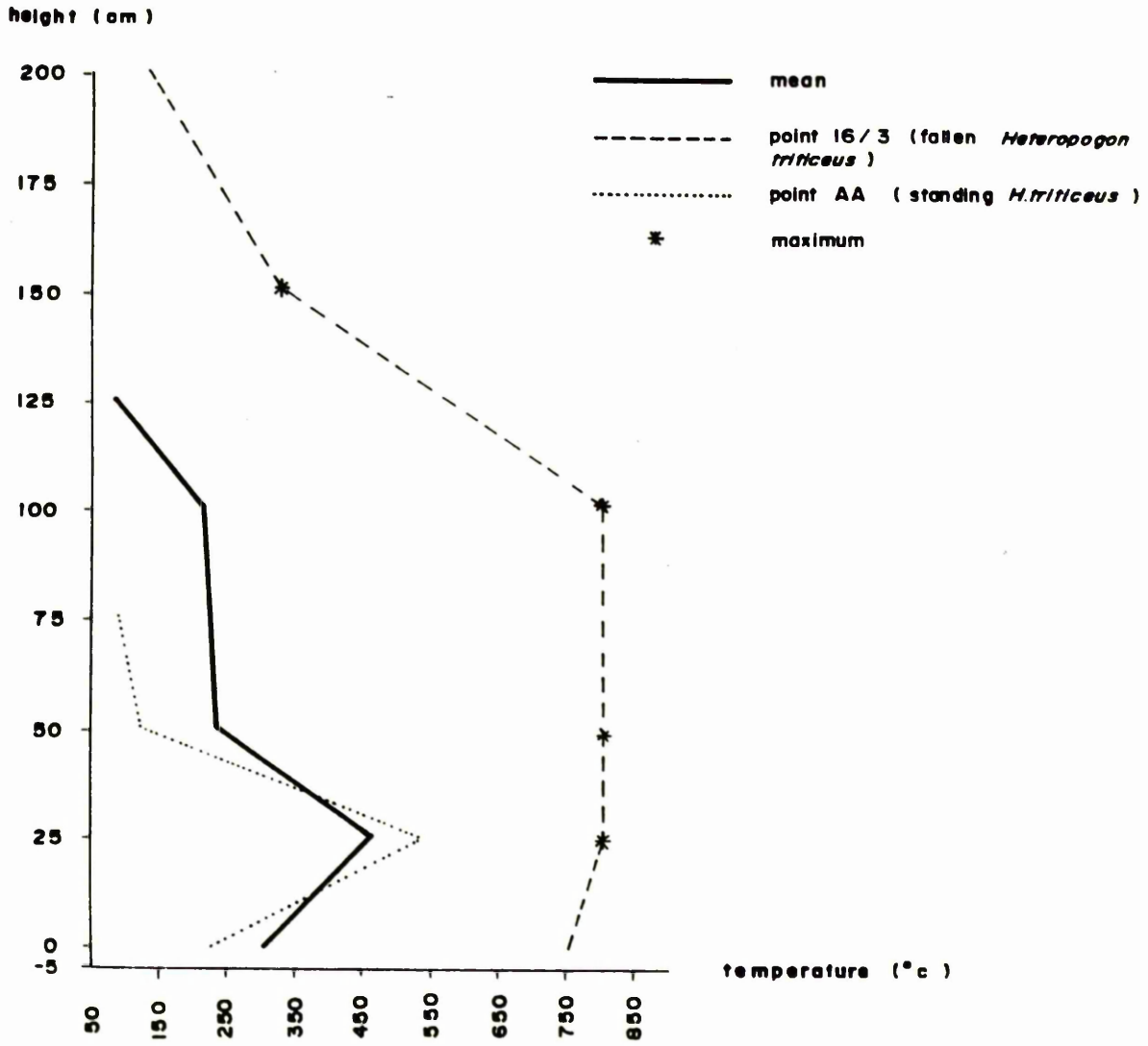


Figure 6.7c. Temperature profile of grass burns.

temperature from ≤75->750°C. Although it cannot yet be finally concluded from the present evidence, this glimpse of the differences in the spatial pattern of temperature between different grass arrangements tends to support the trend already indicated in the study of absolute maximum temperatures recorded with the infra-red pyrometer, which also suggested the strong significance of grass arrangement for fire temperatures. This is a promising topic for further study.

Table 6.9. Summary of the spatial pattern of temperature.

SAMPLING LEVEL	TEMPERATURE (°C)								
	Grass burn			Partial or mixed ground cover burn			Litter burn		
	mean	range	count	mean	range	count	mean	range	count
200 cm	<125	<125-125	1/10	No colour change					
150 cm	<125	<125-325	1/7	83	≤75-≤125	4/15			
(125cm)*							≤125	≤125	1/2
100 cm	>210	≤75->750	6/10	90	≤75-125	6/15	125	125	2/5
50 cm	>230	≤75->750	8/10	108	≤75-275	13/15	131	75-200	3/5
25 cm	>460	≤125->750	8/8	297	≤75-550	8/8	392	≤125-550	3/3
Ground-level	297	75-750	10/10	317	75-550	15/15	438	325-525	6/6
5 cm underground	No pyrometer sample changed colour at this level (30 samples)								

count = number of pyrometers with colour changes to the total number of pyrometers sampled.

* highest level at which a pyrometer changes colour on a leaf litter burn.

Partial ground cover burns displayed burn characteristics of both fuel types. The fairly consistent temperature profile, with the highest temperature occurring at ground-level (mean = 300°C; range = 75-550°C) and at 25 cm above the ground (mean = 300°C; range = ≤75-550°C), is explained by the presence of leaf litter. And, as in the leaf litter burn, the mean temperature dropped to around 100°C (range = ≤75-275°C) at the 50 cm level, with temperatures of around 75°C continuing to occur at a height of 150 cm above the ground, reflecting the presence of the grasses. In the present study, no pyrometer in a pure leaf litter burn, or non-grass burn, changed colour at this level. It is interesting to note that the temperature in a partial ground cover burn is generally lower than in a pure leaf litter burn or pure grass burn, even where litter was at 8 leaves deep among a standing clump of *Apluda mutica*, which did not

SAMPLING LEVEL	STANDING GRASS			50-75% FALLEN			FALLEN GRASS		
	mean	range	count	mean	range	count	mean	range	count
All levels*	277	75-525	12/35	157	≤125-400	8/15	404	≤75->750	15/22
Ground-level *	238	75-325	4/4	≤125	≤125-125	3/3	550	450-750	3/3
25 cm	399	≤125-525	5/5	no sample			>550	450->750	3/3
50 cm	125	125	3/4	263	125-400	2/3	315	≤75->750	3/3
100 cm	No colour change			≤125	≤125-125	3/3	>300	≤75->750	3/3

count = number of pyrometer changed to number of pyrometer sampled.

Table 6.10. Spatial pattern of temperature (°C) of different grass arrangements in grass burns.

sustain the burn well. It is possible that the presence of partially dry or moist fuel may affect the combustion of the dry fuel.

Pyrometers located in the horizontal plane also showed an interesting pattern. Temperature tended to drop considerably down the range of the following categories: from 1) those pyrometers placed within the heart of a dry grass clump, to 2) those contacting the side of a grass clump, to 3) those set away, but still very near, to a grass clump. For example, in plot 1, a burn on fallen *Heteropogon triticeus*, the temperature at 50 cm above the ground for the three placements were 400°C, 125°C and <75°C (no colour change) respectively, although at the ground-level, temperatures were more similar, at around 120°C. It would be worthwhile to measure the spatial distribution of temperature on the horizontal plane at such close intervals as on the vertical axis. Horizontal temperature variation at this level must have an important impact on the distribution of ground cover, and in particular, on the survival chances of small seedlings.

6.3.3 Rate and pattern of fire spread

The detailed study of fire spread and flame height was carried out at two minute intervals on the burns in the *Dipterocarpus* 1 stand. Results from this study will be presented after a general discussion of

the mean speed of fire spread taken from all burns.

6.3.3.1 Mean speed of fire spread

The methods used to derive the mean speed of spread (cm s^{-1}) are described fully in Section 4.2.1.3. The results are presented in Table 6.11. It was found that the mean speed of spread in both ground cover and leaf litter burns was 0.83 cm s^{-1}, but the range in the ground cover burns was much greater (0.17-3.33 cm s^{-1}) when compared with the leaf litter burns (0.17-1.67 cm s^{-1}).

As previously shown, burns with a higher maximum temperature spread faster than ones with a lower temperature. This is true for all fuel types. But while there does not seem to be a clear explanation for this in the litter burns employed in this study, several explanations are apparent for the ground cover burns. As is the case with the maximum temperature, the mean speed of spread correlates well with the initial air temperature (df=15, r^2=0.397, r=0.63, p=0.01; Fig.6.8), and also with grass fuel arrangement (df=15, p=0.008). The higher the air temperature, the faster is the speed of spread. Likewise, a fallen grass arrangement (mean = 1.33 cm s^{-1}; range = 0.5-2.95 cm s^{-1}) allows fire to travel faster than a standing arrangement (mean = 0.5 cm s^{-1}; range = 0.17-0.83 cm s^{-1}). This pattern appears to be even stronger when only the grasses *Heteropogon triticeus* and *Apluda mutica*, which are comparable in stature, are

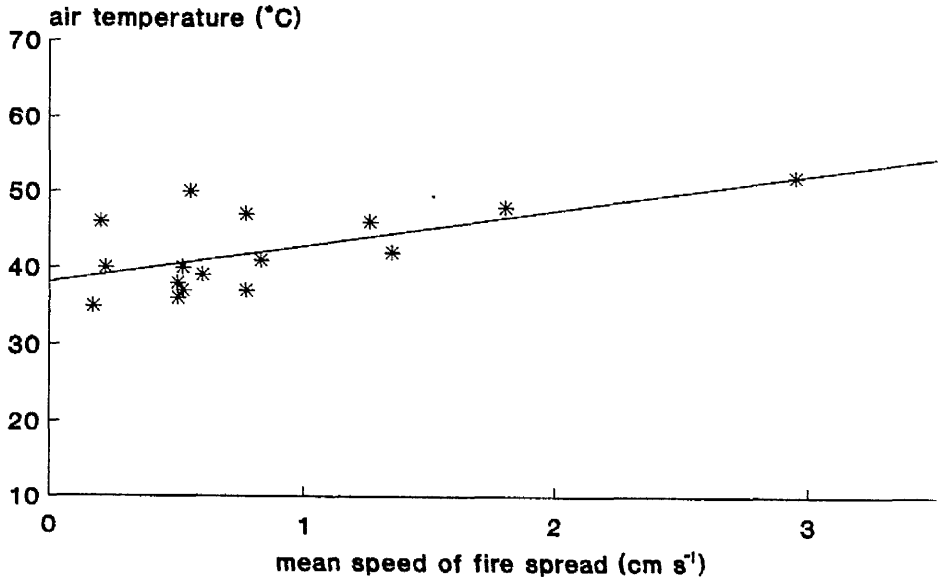


Figure 6.8. Regression between air temperature and the rate of fire spread in ground cover burns.

FUEL TYPES	MEAN	RANGE	COUNT	S	V
Ground cover burn	0.83	0.17-2.95	16	0.43	84.5
Leaf litter burn	0.83	0.17-1.67	12	0.3	61.3

VARIABLES	MEAN SPEED OF SPREAD (cm s^{-1})		
	Ground cover burn		
	mean	range	count
Fallen grass (70-100% fallen)	1.33	0.5-2.95	6/6
Standing grass (0-50% fallen)	0.5	0.17-0.83	10/13
Dense-very dense ground cover (scale 5.4-5.5)	1.17	0.17-2.95	8/8
Moderately dense ground cover (scale 3.2-4.4)	0.5	0.17-0.83	8/11

Table 6.11. Results of mean speed of fire spread (cm s^{-1}).

considered, reflecting the importance of the grass species for fire behaviour.

The moisture content of the leaf litter is another factor that appears to have some significant influence over the speed of spread, at least from this study of the ground cover burns. It seems that a fire may burn faster on leaf litter with a lower moisture content. However, more experiments are required before any firm conclusions can be made.

6.3.3.2 Pattern of fire spread

The pattern of fire spread was mapped at two minute intervals from the fourth minute after ignition to the 26th. The method is fully described in Section 4.2.1.3. Essentially, this study was restricted to the two burns in the *Dipterocarpus* 1 stand, but a smaller scale practice study was made on burn No.1 at the beginning of the fire season.

Burn No.1 was well-sustained on a largely homogeneous distribution of fallen *Heteropogon triticeus*, on a flat piece of land. The pattern of fire spread is more or less circular, with a tendency towards a regular oval shape where the fire spread is elongated by the prevailing wind direction (Fig.6.9a). On the other hand, the patterns of burn on plots A and D in the *Dipterocarpus* 1 stand partly reflect the heterogen-

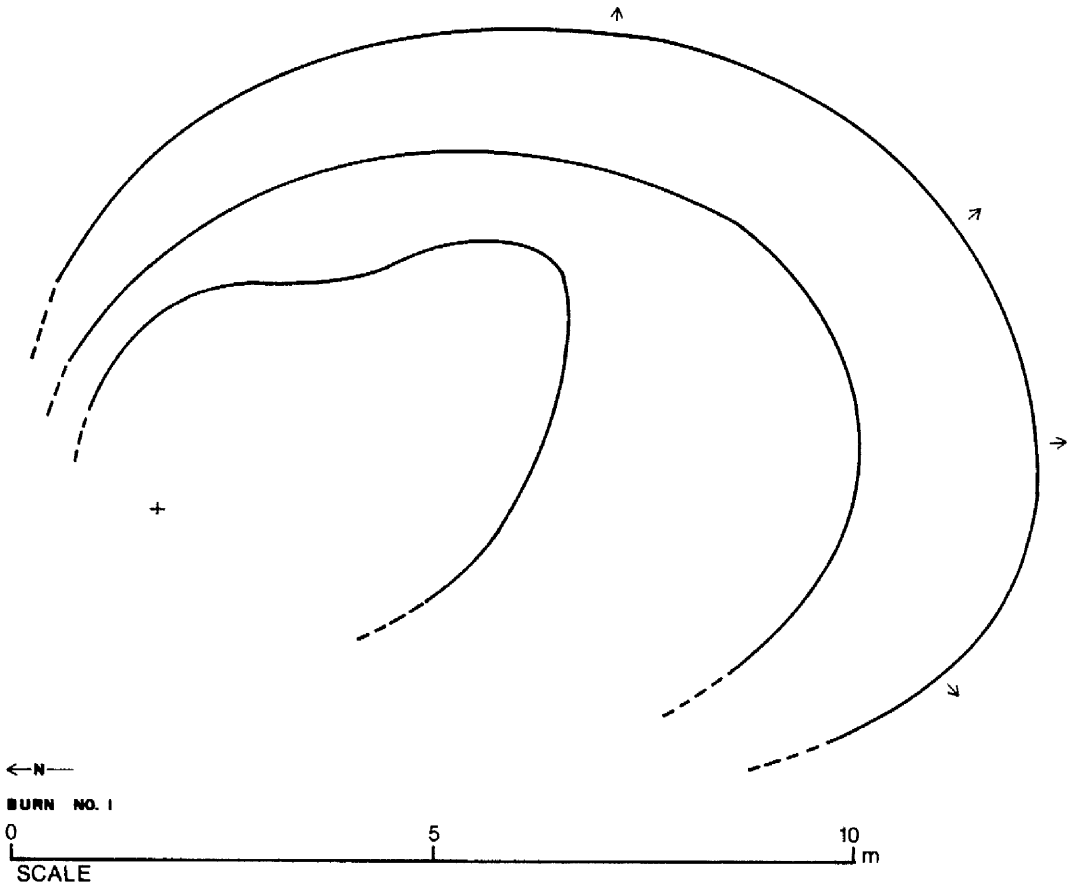


Figure 6.9a. Pattern of fire spread, burn 1, (29 January 1988).

eous distribution of fuel, with a mixture of several dominant grass species, and a high proportion of non-grass ground cover.

The patterns of fire spread here were essentially circular, although some distortions occurred at a point where the burn was hindered or obstructed by less sustainable sources of fuel. This was especially evident in the plot A burn (Fig.6.9b). The fire spread in plot D was rather more complex towards the last 8 minutes of study (Fig.6.9c). The pattern became less predictable, with a long fireline snaking backwards and forwards and slithering on its side. This was probably caused by the combined factors of changing wind directions, slope, and the patchy distribution of fuel sources. The wind changed direction constantly during this burn, and it became a partial back fire burn, although a head fire was intended at the initial ignition. However, because the

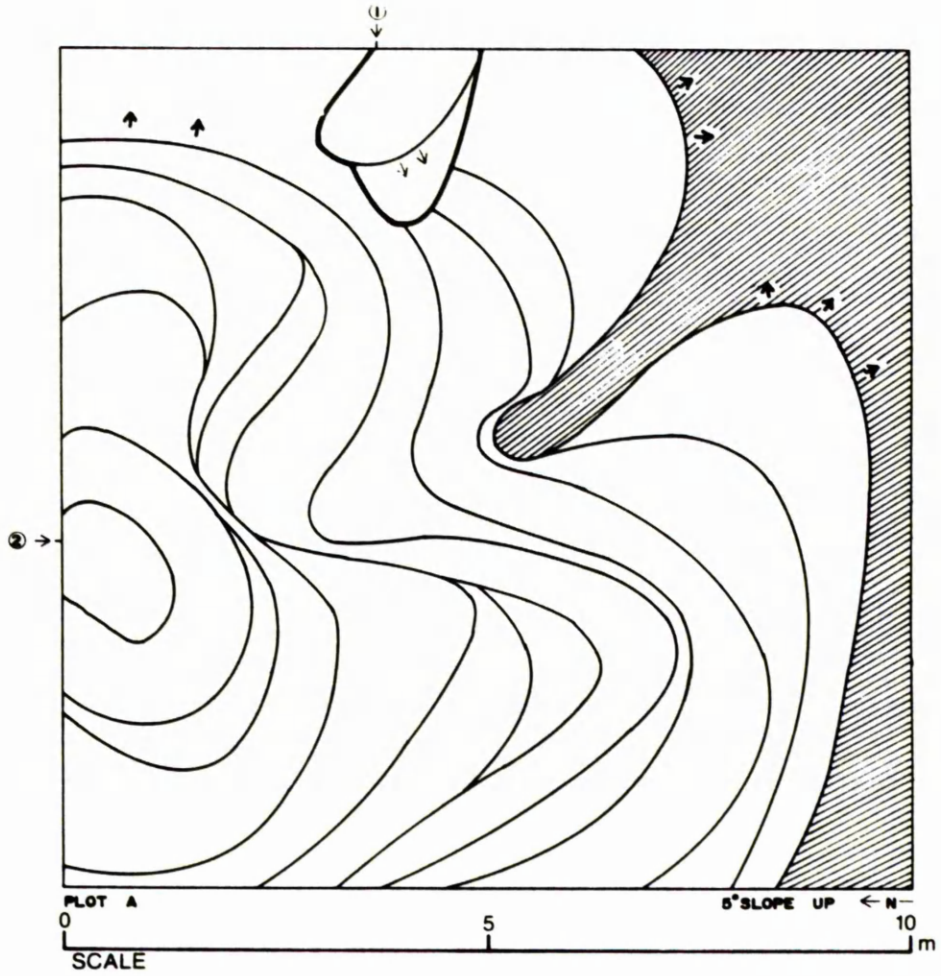


Figure 6.9b. Pattern of fire spread, plot A, (24 February 1988).

intention to set a head fire was a priority, plot D was fired upslope, while plot A was fired downslope. Even though the slope was very slight (at 5°), slope influence shows clearly in plot D, where the fire tended to spread much more readily upslope. Both plot A and D burns were poorly sustained, leaving some odd patches of unburned fuel. Indeed, the plot A burn was only sustained on the second attempt at ignition, after the first spread was extinguished by a change in wind direction.

Such behavioural patterns are consistent with the general observations made on other fires, both experimental and non-experimental. Ground cover burns tend to spread in a circular pattern when it is windless and the burn is on a flat land; otherwise they spread in an oval shape. Leaf litter burns, on the other hand, tend to move in a linear front. But the regularity of these basic patterns varies much with the

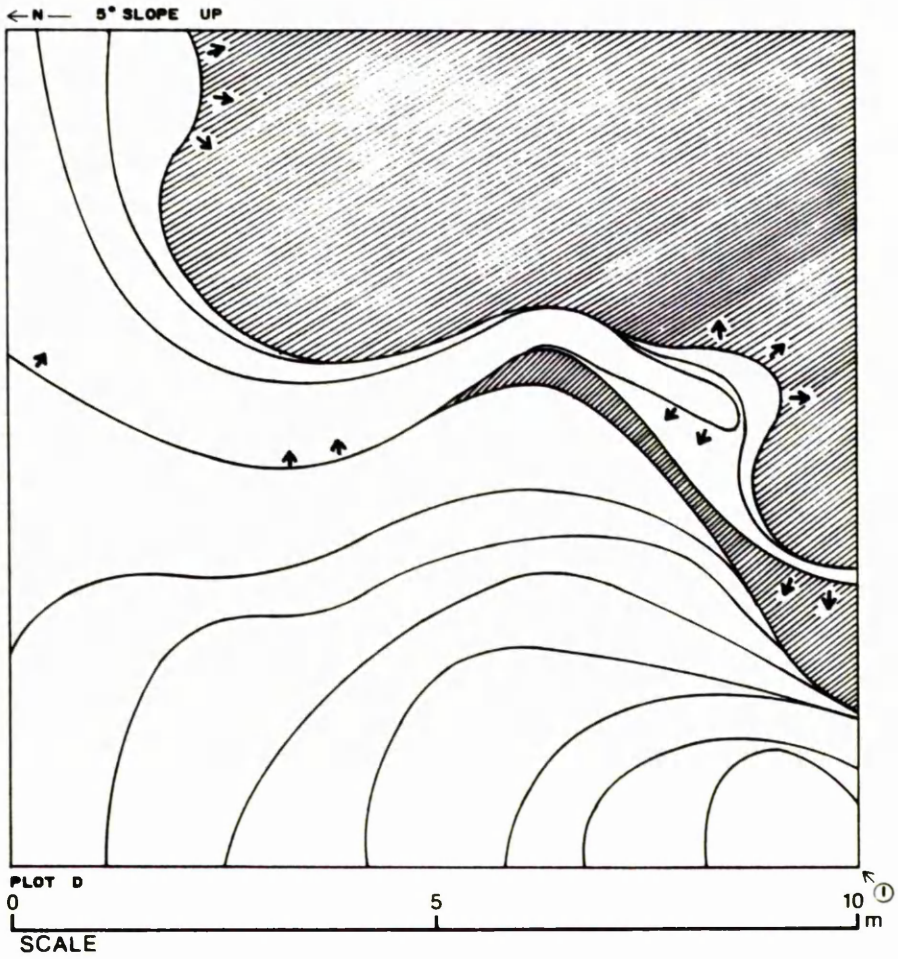


Figure 6.9c. Pattern of fire spread, plot D, (25 March 1988).

distribution of fuel moisture content, fuel biomass, fuel composition, fuel arrangement, and, of course, wind changes. Where the ground cover is mixed and partially dry, fire spread tends to be irregular and patchy, often splitting into long narrow tongues that snake into sustainable fuel patches as they are dictated to by the wind. In contrast, burns on a dry and homogeneous grass cover tend to move evenly, leaving fewer areas unburned, although in a large burn, fire may break into many arched fronts. As with ground cover, leaf litter also burns patchily when it is partially dry.

In terms of seasonal timing, the earliest burns sustained on an open stands with homogeneous grass cover tend to be patchy, although this pattern can change quickly as the dry season proceeds. By contrast, fires in the late season, burning on a mixed ground cover, following a

period of leaf shedding (e.g. late March), spread quite evenly when climatic conditions are favourable.

6.3.3.3 Flame height and frontal fireline intensity

Table 6.12 gives the sequence of maximum flame height, and derived values of maximum fireline intensity in plot A and D burns, with an additional note on burn No.1. Maximum heights of fire flame are also portrayed in Fig. 6.10a, b, c. Both plot A and D were low fireline intensity burns, with a mean maximum energy output of 217 kW m^{-1} (range = 19-1173 kW m^{-1}) and 102 kW m-1 (range = 27-260 kW m^{-1}), and a mean maximum flame height of 0.8 m (range = 0.3-2 m) and 0.6 m (range = 0.35-1 m) respectively.

A gush of wind at the 26th minute of the plot A burn blew up the flame to 1.5-2 m, giving a high fireline intensity of 627-1173 kW m^{-1}. If that moment is discounted, the mean maximum fireline intensity in plot A would be 120 kW m^{-1} with a mean maximum flame height of 0.7 m. Measurements in burn No.1 only lasted up to the 8th minute before the fire was put out, and thus only three readings were taken. It is suggestive, however, that this burn on fallen *Heteropogon triticeus* would have turned

MINUTES AFTER IGNITION	PLOT A		PLOT D		BURN 1	
	L	I	L	I	L	I
4	0.60	85.6	0.55	70.8	1.80	932.5
6	0.65	101.9	0.60	85.6	1.50	627.4
8	0.35	26.5	1.00	259.8	0.70	119.7
10	0.85	182.5	0.35	26.5		
12	1.00	259.8	0.75	139		
14	0.30	19	0.50	57.6		
16	0.65	101.9	0.40	35.4		
18	0.70	119.7	0.80	160		
20	1.00	232.4	0.60	85.6		
22	0.70	119.7	0.75	139		
24	0.95	232.4	0.60	85.6		
26	2.00	1172.6	0.70	119.7		
28	0.75	139	0.65	101.9		
30			0.75	139		
32			0.80	160		
34			0.45	45.8		
36			0.35	26.5		
MEAN	0.81	216.9	0.62	102.2	1.33	559.8

L = flame height (m)

I = fire line intensity (kW m^{-1})

Table 6.12. Maximum flame height (m) and fireline intensity (kW m^{-1}).

out to bear a relatively high overall fireline intensity of around 550 kW m^{-1} (range = 120-933 kW m^{-1}) with an average maximum flame height of over 1 m (range = 0.7-1.8 m). Likewise, the late burn No.16 in the *Shorea* 1 stand on fallen *H.triticeus*, had an average flame height of around 1 m or over ($I \geq 260$ kW m^{-1}), but with a wide range from around 0.5-2 m (I = 58-1173 kW m^{-1}). The early burn No.12 on standing *H.triticeus*, and the back burn, No.15, on fallen *H.triticeus*, were more comparable to the *Dipterocarpus* 1 burns, with an average maximum flame height of between 0.5-1 m (I = 58-260 kW m^{-1}).

This suggests that ground cover burns in these dry dipterocarp forest formations tend to be of low fireline intensity (I), from around 20-250 kW m^{-1}, although a higher fireline intensity from around 400-1000 kW m^{-1} can occur sometimes, under a strong wind for instance. Much more study, of course, needs to be done. With respect to the present thesis on fire timing, however, it can only be said that fireline intensity does not neccessarily correspond strictly with seasonal timing. Both high and low fireline intensities can occur in both the early and the late season. Nevertheless, it is possible that the hot and dry environment, and the relatively stronger prevailing wind in March (see Table 5.3), might induce a higher proportion of high fireline intensity burns than in any other fire season month.

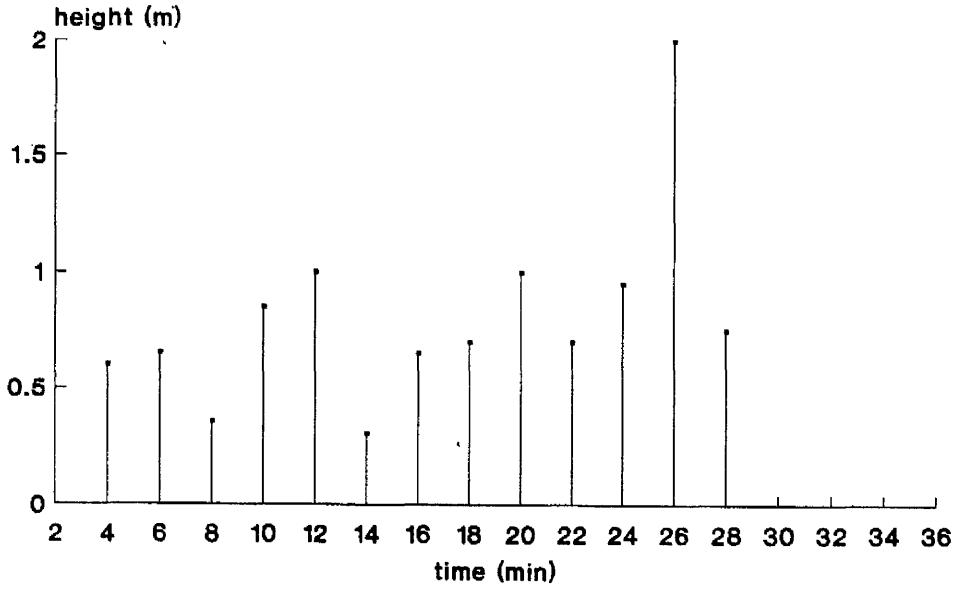


Figure 6.10a. Sequence of maximum flame height (m) at two minute intervals, plot A, *Dipterocarpus* 1 stand (24 February 1988).

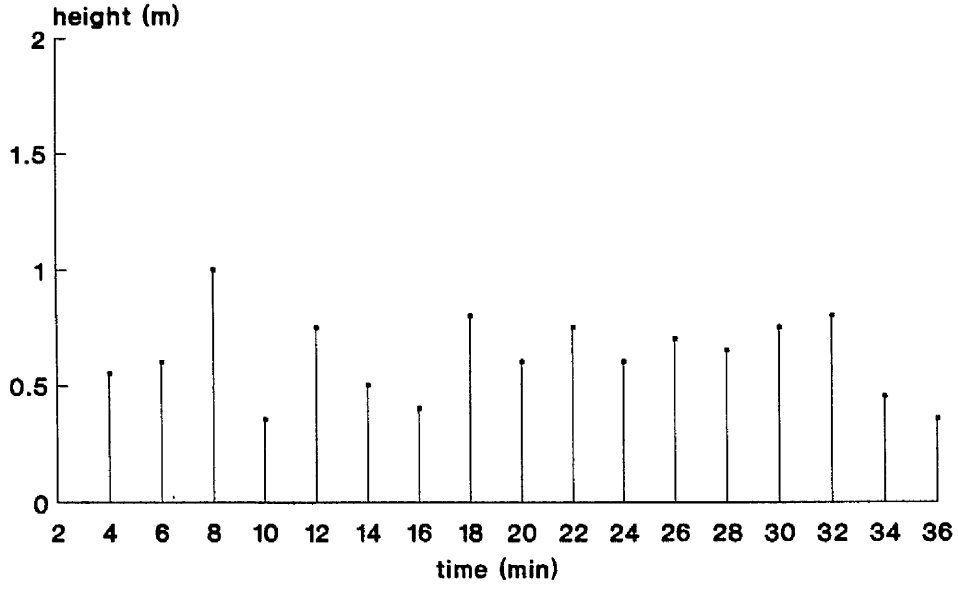


Figure 6.10b. Sequence of maximum flame height (m) at two minute intervals, plot D, *Dipterocarpus* 1 stand (25 March 1988).

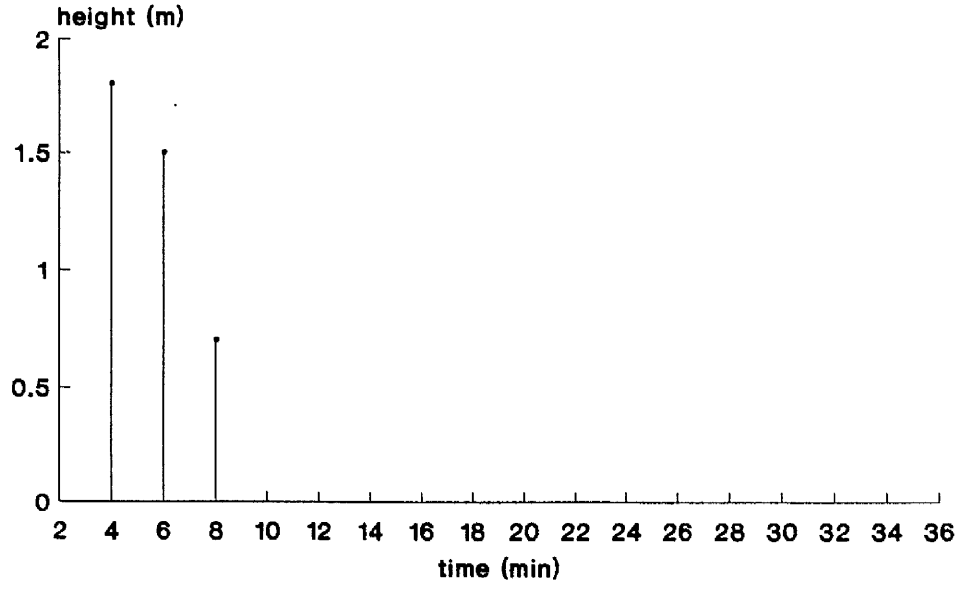


Figure 6.10c. Sequence of maximum flame height (m) at two minute intervals, burn 1, *Shorea* 2 stand (29 January 1988).

6.4 Discussion

Several significant relationships have been demonstrated between certain characteristics of fire behaviour and some variables in the conditions for a burn. Fuel moisture content, as well as leaf litter depth, appear to be the most crucial factors for marginal sustainability, and thus they determine the earliest burns. It was found that the critical moisture content for grass is around 38%, and around 9% for leaf litter at more than 1-2 leaves deep.

Once a burn is well-sustained, these variables play a lesser role in influencing fire behaviour, although an increase in leaf litter depth sometimes also increases fire maximum temperature, particularly at 6-7 leaves deep. At the level where sustainability is uninhibited, external factors seem to become of primary importance. Most striking is the positive inter-correlation in ground cover burns between maximum temperature, mean speed of fire spread, and air temperature, where an increase of one leads to an increase in the others.

Equally important is the arrangement of grass stalks. It was found that fallen clumps tend to produce a higher temperature and faster speed of spread than standing ones. Of the two main grass species studied, only *Heteropogon triticeus* (Fig.6.11) collapsed in the dry season, while *Apluda mutica* (Fig.6.12) always remained upright. Although the moisture content of fallen *H.triticeus* (mean = 28.9%; range = 17-36.5%) tends to be somewhat lower than the standing moisture content (mean = 34%; range = 28-44.7%), the difference is hardly marked. However, as noted in Chapter 5, the drying, partially-fallen *H.triticeus*, if not trampled down by grazers, was further flattened completely after a heavy fall of the Northeast monsoon in early February. *A.mutica*, on the other hand, remained standing. This suggests that the different structural make-up of each grass species may have a considerable control over its possible arrangement, once moisture stress reaches a certain level, probably with a moisture content somewhere below 40% in the case of *H.triticeus*. The structural strength of *Eulalia bicornuta* (Fig.6.14) gave way totally prior to the arrival of the Northeast monsoon, with a moisture content below 28%. In the case of *A.mutica*, however, it is not known whether the grass would fall if moisture content became lower than it did (36%) during the year of this study. The grass *Chrysopogon orientalis* (Fig.6.13) did not collapse either; its stems slanted at 45° angle.

Generally, therefore, there are two different burning regimes within the dry season. Where canopy cover is significant, the first burning stage is determined by the accumulation and moisture content of

leaf litter shed on to the forest floor. The result is primarily a leaf litter burn where the ground cover is sparse, or a partial ground cover burn where the ground cover is thin or moderate. Where the ground cover is dense, and primarily consists of grasses, the leaf litter may be a secondary source of fuel, with grass arrangement and air temperature playing the key roles. Air temperature is generally higher under an open canopy, and is usually accompanied by low humidity, and this may cause the grass to burn earlier in very open formations, as in many *Shorea* associations. However, during the year of study, it was the onset of the Northeast monsoon in February which largely changed the fuel arrangement in some major grass species, as in partially-dried *Heteropogon triticeus*, by flattening them, and thereby preparing the forest formation for a second stage of burning, when they dried up again after the rains. The result was a high temperature fire with a faster speed of spread. The likelihood of such fire occurrences increases as the burning weather progresses with the dry season, with March providing the maximum fire regime in the year of study.

Partial ground cover burns and leaf litter burns also occurred primarily in March, with a second burn occurring in some places where a considerable amount of leaf litter continued to fall in February after the first early burn in the previous month. The area of burn No.12 in the *Shorea* association is an example of this.

Fire spread in ground cover burns is essentially circular, but within this generalization, two main patterns are observed. On a mixed ground cover with heterogeneous fuel distribution, the fire tends to spread patchily, particularly when fuel is partially dry. In contrast, fire spreading on a homogeneous grass cover is even and continuous. Nevertheless, both patterns can occur on both ground cover types, with patchy burn occurring very early in the fire season on partially dry homogeneous grass cover, and the even burn sometimes occurring in mixed ground cover when burning conditions are favourable, usually in the late fire season.

Fireline intensity (I) in the dry dipterocarp forests during the year of study ranged from 20->1000 kW m^{-1} throughout the dry season, with flame height varying from 30 cm to around 2 m. Average fireline intensity in the *Dipterocarpus* association burns was >100 kW m^{-1}, although a gush of wind can increase fireline intensity considerably, even up to >1000 kW m^{-1}.

Temperature duration in most well-sustained head fires is extremely brief in all fuel types, with a sudden temperature rise and drop

Figure 6.11. Experimental grass species, *Heteropogon triticeus* (R.Br.) Stapf.ex Craib, 1.70 m high (scale 1:3).

Figure 6.12. Experimental grass species, *Apluda mutica* L., 1.50 m high (scale 1:3).

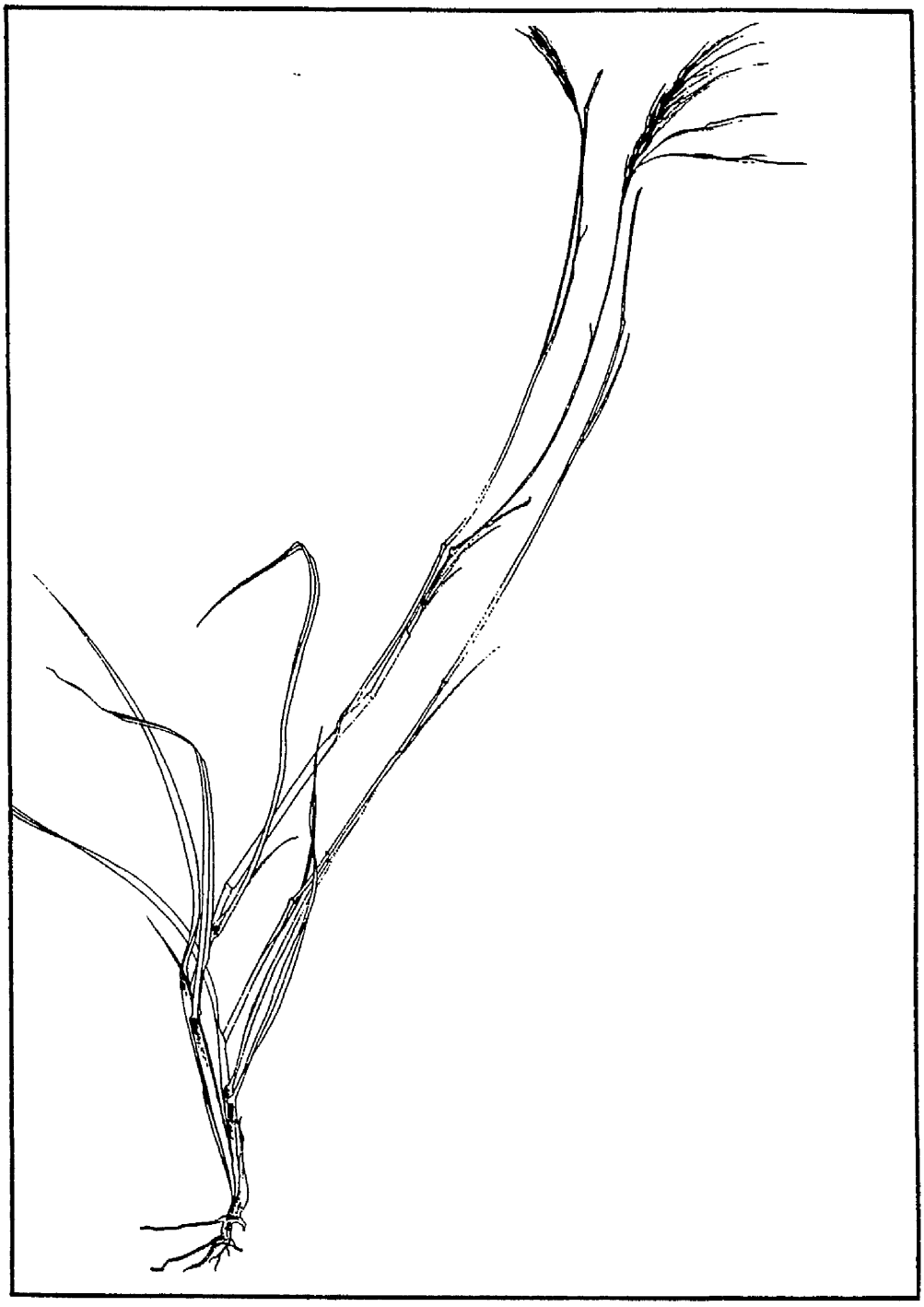


Figure 6.13. Experimental grass species, *Chrysopogon orientalis* A.Camus, 70 cm high (scale 1:2).

Figure 6.14. Experimental grass species, *Eulalia bicornuta* Bor., 25 cm high (scale 1:1.5).

in one single high peak. The mean maximum temperature is around 600°C; mean duration of maximum temperature of the highest 50°C bracket is less than 10 s; and the mean duration of temperature above 50°C is around 4 min. However, if all the sustained burns are included, the mean maximum temperature of both ground cover and leaf litter burns drops to around 500°C, with the former exhibiting a greater range, from almost 200°C to nearly 900°C, the latter from around 200-700°C. The highest temperature of all was recorded in a head fire burn on fallen *Heteropogon triticeus*, ranging from over 700°C to almost 900°C.

The mean duration of maximum temperature of the highest 50°C range is around 15 s for both fuel types, although the mean duration of temperature above 50°C is longer in ground cover burns (*c.*4 min 30 s) than in leaf litter burns (*c.*3 min 30 s). A brief duration of maximum temperature tends to be associated with high maximum temperatures in ground cover burns.

The mean value of mean speed of spread is also similar in both fuel types, at around 0.8 cm s^{-1}, but the range is greater in ground cover burns, from 0.17 cm s^{-1} to almost 3.33 cm s^{-1}, while, for leaf litter, the range is from 0.17-1.67 cm s^{-1}. The fastest rate of spread tends to occur on fallen *Heteropogon triticeus*, with the mean of around 1.67 cm s^{-1} (range = 0.55-2.95 cm s^{-1}).

Study of the spatial pattern of temperatures, using 'thermocolor' pyrometers, correlates reasonably well with the burning experiments using the infra-red pyrometer, although the former records only minimum values of the maximum temperatures attained in a burn. Leaf litter burns with the highest temperature at ground-level, with a mean of over 400°C, supported the conclusions of earlier work done by Stott (1986). But, unlike Stott, who found the highest temperature in the ground cover burn to occur at 50-100 cm above the ground, the highest temperature reached in ground cover burns in this study were at 25 cm above the ground, with a mean of around 450°C. Perhaps this is partly because the grass burns in this study were not always well-sustained, and many burns were on collapsed grass clumps, with an average fuel height of around 30 cm.

The spatial pattern of temperatures in leaf litter burns is quite consistent, with the highest temperatures always occurring at ground-level, with a mean of *c.*400°C. In contrast, in grass burns, the temperature range is great at most levels sampled, especially from ground-level up to 100 cm high, and range from $\leq$75-$\geq$750°C. The highest temperature occurred on fallen *Heteropogon triticeus*, particularly from a head fire burn in March, where a relatively high temperature was

recorded even as high up as 2 m above the ground (125°C). But, generally, in all fuel types, the mean temperature starts dropping from 50 cm above the ground, with some pyrometer samples remain unchanged, indicating a temperature of less than 125° C, and probably much lower.

The spatial pattern of temperature in partial ground cover burns reflects the essential characteristics of both leaf litter and grass burns, with the highest temperature attained at both the ground-level and at 25 cm above the ground, with a mean of around 300°C. This temperature value is the same as that found by Stott (1986) in his experiment on a partial ground cover burn.

Much yet remains to be studied. Apart from the need to develop further research on grass fuel arrangement in different species, there are other variables that appear to have a significant influence over fire behaviour, notably the difference between head and back fires. This is likely to be a crucial factor for marginal sustainability, maximum temperature reached, and duration of maximum temperature. Detailed work is also needed on the spatial pattern of temperatures in the horizontal plane, with the measurement taken at closer intervals.

CHAPTER 7.

EXPERIMENTAL RESULTS III: direct effects of the burns and vegetation recovery

7.1 Introduction

The ecological effects of the experimental burns are reviewed in this chapter, which is divided into two main sections. The first section evaluates the direct effects of fire in all experimental burns, while the second presents a more detailed analysis of vegetation recovery after fire, and phenological adaptations to fire. This second section is restricted to the permanent experimental plots in the *Dipterocarpus* 1 stand.

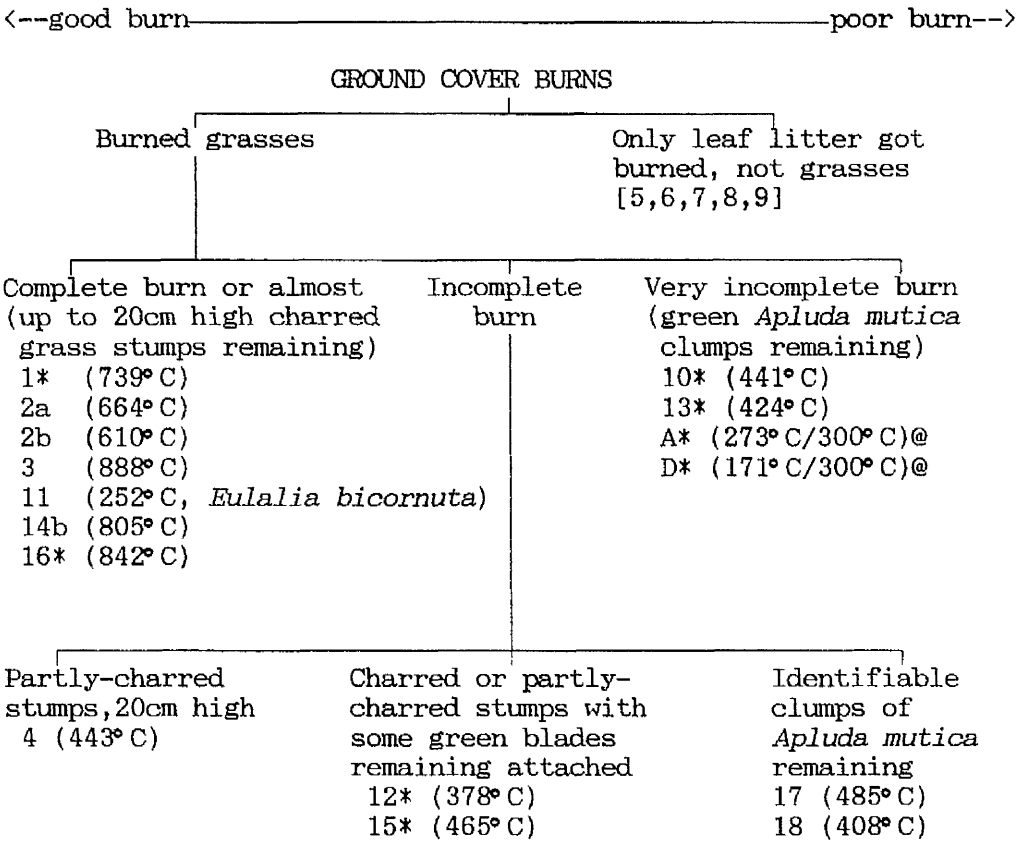
7.2 The direct effects of dry season burns

Fig.7.1 summarises the direct effects of ground cover burns on the grasses. Wherever applicable, the effects of fire on seedlings and logs, and the height of leaf browning and curling, are also given in the notes following the diagram.

Direct effects on the grasses are classified into complete burns or almost complete burns, partial burns, and very incomplete burns. 'Complete burn' refers to those cases where all of the above-ground parts of the grasses were totally burned (No.11), or where only charred remains were left in the form of blackened grass stumps, up to around 20 cm high (No.1, 2a, 2b, 3, 14b, 16). Except for burn No.11, which was set on the rather fine grass, *Eulalia bicornuta*, the other 'complete burns' were on standing (No.2a, 2b) and fallen (No.1, 3, 14b, 16) *Heteropogon triticeus* at varying dates and moisture contents (see burn variables and results in Tables 6.1 & 6.2). All 'complete burns' on *H.triticeus*, however, were the hottest burns in the experiments, with maximum temperatures from 600°C upwards. In contrast, the less complete burns are all associated with maximum temperatures of below 500° C.

At the other extreme, 'very incomplete burn' describes those cases where there were some whole grass clumps remaining green directly after the burn, especially in *Apluda mutica*. Many clumps of this grass species were left largely unburned in both plots A and D, while most of the other species were not. And, although the flames were fairly well-sustained through the presence of leaf litter, burns No.10 and 13 on *A.mutica* still left only a 50-90 cm high charred mark at the base of the green grass clumps. Observations on plots A and D, however, showed that

Figure 7.1. Direct effects of ground cover burns.



@ = the first value was measured from a single point with the infra-red pyrometer; the second value is the mean temperature at ground-level measured by the 'thermocolor' pyrometers.

Note on burns with asterik (*)

1
- some 5-10cm high charred grass stumps.
- seedling stems slightly charred or not at all, but all died several days later.
- dry *Cycas siamensis* did not burn.
- 5cm diameter branch burned.
- 20cm diameter log did not burn.
- >1.80-<5m high leaf browning and curling.

16
- some 10-15cm high charred grass stumps.
- seedlings burned.
- logs burned.
- 6-10m high leaf browning and curling.

Incomplete burn

12
- 17-25cm high charred grass stumps, some with 7-10 green blades attached.

15
- 80% of grass stumps were partly charred, 7-16cm high.

- 20% of grass stumps had greenblades or long stalks attached. Mostly 1-2 blades/stump, but the highest had 5-6 blades/stump.

Very incomplete burn

10 - 50cm high charred mark on the bases of green *Apluda mutica* clumps.

13 - 45-90cm high charred mark on the bases of green *Apluda mutica* clumps.

A - 21% ground cover remained, with 10% grasses and 11% woody plants.
- *Apluda mutica* remained green, but withered a few days later.
- some seedling stems charred, but most died several days later: 1-2 specimens/species survived.

D - under 10% ground cover remained, with <5% grasses and 5% woody plants.
- *Apluda mutica* remained green, but withered a few days later.
- some seedling stems charred, but most died several days later: 1-2 specimens/species survived, except all *Shorea obtusa* died, 4 from 10 *Dipterocarpus tuberculatus* survived.

these 'unburned' clumps of *A.mutica* later withered and died a few days after the burn. They would, therefore, serve as a future fuel, provided that the dry remains do not rot before the next fire.

The middle category, 'partial burn', includes a range of partially burned grasses, from remains of partly charred grass bases (No.4), to remains of grass bases, with a few green grass blades still attached (No.12, 15), to, finally, remains of burned, but still identifiable, clumps of grass (No.17, 18). As with 'very incomplete burns', this type was also common in *Apluda mutica*. It can thus be concluded that *A.mutica* does not combust as well as the other grass species, at least under the conditions met during the 1988 dry season.

While most burns were around 4 m x 4 m, plots A and D (very incomplete burn) and plot 1 and 16 (complete burn) were comparatively larger burns, from 6->10 m long (A & D are 10 m x 10 m; 1 & 16 are free burns with no fire breaks). In burn No.16, all the seedlings were heavily burned; so were logs, including one with a diameter of >30 cm. Seedling stems in burn No.1, on the other hand, were hardly charred, although most of their leaves were curled. A dry specimen of *Cycas siamensis* did not burn either. This was because there were no grass clumps, nor much leaf litter,

near the seedlings and the cycad. Frontal fireline intensity in the burn No.1 fire, however, was intensive enough (*c.*400 kW m^{-1}) to burn a branch of 5 cm in diameter, although a log of 20 cm in diameter did not burn.

The low fireline intensity in both plot A (mean = 217 kW m^{-1}) and D (mean = 102 kW m^{-1}) left only some seedling stems charred. Nonetheless, most of the 'unburned' seedlings in these two plots, as well as in plot 1, died within a week, several days after being exposed to the heat of surface ground fires. But fires in plot A and D still left 1-2 seedling specimens of each sampled species alive, with the exception of *Shorea obtusa* in plot D, which all died, and *Dipterocarpus tuberculatus* in the same plot, where 4 specimens out of 10 samples survived the burn (no *D.tuberculatus* was sampled in plot A). Death in a seedling was recognized by scratching the base of the stem to the cambium layer to see if it had remained green or had turned dry.

Height of leaf browning and curling on trees and saplings were not evident in burn A and D. Neither was it clear in burn No.1, where leaves of a 1.80 m high sapling were curled to the top, but tree branches at 5 m high were not affected. Thus, the height of leaf curling and browning here must be between 2 m to under 5 m. On the other hand, in burn No.16, it was as high as 6-10 m. This kind of burn would certainly injure nests built relatively low at around 8-10 m high. However, it was interesting to note that in this particular stand of the *Shorea* association with dense, 1 m tall *Heteropogon triticeus*, no such low nests were found, although bird nests at this height were noted elsewhere (see Section 2.4.2).

To conclude, then, three main points are apparent from these observations on the direct effects of the ground cover burns. First, a high temperature fire above 600°C produces an almost complete grass burn, and such a fire is associated mainly with *Heteropogon triticeus*. Secondly, combustion in the grass *Apluda mutica* is often partial, resulting in 'very incomplete burns'. And thirdly, grass clumps, and most seedlings that have been exposed to some degree of heat from a passing surface fire, but are not charred and appear to be left 'unburned', still usually die within a week of the burn. They then dry up and probably serve as potential fuel for a future fire. However, a few 'unburned' seedlings do survive burns with a low fireline intensity.

7.3 Vegetation recovery in the *Dipterocarpus* 1 stand

Plots A, B, C and D underwent ecological stresses in 1988. A and D were burned on 24 February and 25 March respectively. Both were

poorly-sustained burns of low fireline intensity, low temperature, but long temperature durations, at least at the points of measurement. The burn in plot A yielded a mean fireline intensity of 217 kW m^{-1} and plot D 102 kW m^{-1}. The mean maximum temperature in both plot A and D reached around 300° C at ground-level, although the mean maximum temperature for all ground cover experimental burns in this dry season was 518°C. The duration of the highest 50°C temperature bracket in A lasted 35 s, while, in D, the duration was as long as 75 s (mean = 15 s). A, however, was a head fire (mean = <10 s), whereas D was a partial back fire (mean = 55 s). The duration of temperature measurements above 50°C were 7 min 20 s and 6 min 5 s for plots A and D respectively (mean = 4 min 55 s). The mean speed of spread in D was about 0.77 cm s^{-1}, less than in other experimental burns (mean = 0.83 cm s^{-1}), although in A, it was even lower at 0.5 cm s^{-1}.

Plots B and C were both control plots, but the former was heavily disturbed by elephants, particularly in January and April. Thus

MONTH	PLOT A	PLOT D	PLOT B	PLOT C
1987 Oct	ground cover species count*			
Nov	SW monsoon ended on the 29th			
Jan	elephants visited plots, especially B			
	ground cover species count			
Feb	burned on the 24th	NE monsoon fell from the 4th		
Mar		burned on the 25th		
Apr	SW monsoon fell from the 6th			
	elephants and gaur visited plots, esp. B			
Aug	elephants visited plots			
Nov	elephants and gaur visited plots			
1988	ground cover species count			

Flood made site inaccessible in September and October 1988.
* also includes estimation of species cover distribution.

Table 7.1. Disturbance events on the *Dipterocarpus* 1 plots.

A and D are burned plots of one month difference, while B represents a frequently trampled and grazed area, and C is the least disturbed of all.

All the major disturbance events occurring in these plots during October 1987 to November 1988 are reviewed in Table 7.1.

7.3.1 Ground cover composition and cover area

Table 7.2 and Fig.7.2 show ground cover composition in terms of the cover percentage of the two main vegetation categories, namely the grasses and the non-grass species. 'Grasses' refer to the order Glumiflorae (Cyperales), which includes the members of Gramineae family, as well as members of the Cyperaceae, or sedge family, although the ground cover of the latter was negligible. The 'non-grass' species are divided into woody plants and non-grass herbaceous growth, the latter being simply referred to as 'herbs'. This set of data was collected in October 1987, January 1988 and November 1988. In addition, Table 7.3 and Fig.7.3 present the monthly estimation of overall ground cover percentage from October 1987 to November 1988.

It must be mentioned here that the figures representing ground cover composition in Table 7.2 have been calibrated to fit with the general estimation of overall ground cover in Table 7.3. This was neccessary because the composition of different vegetation types was derived by adding up the cover values of individual species. Since cover area of one plant species often overlaps another, the uncalibrated result is normally a figure greater than the actual ground cover area. Thus calibration is neccessary for easy data reading. It is calculated by the following equation:

$$\frac{\text{Sum of cover value of vegetation type}}{\text{Total sum of all ground cover species}} \times \text{estimated ground cover percentage}$$

It is rather unsatisfactory to compare 1987 with 1988 data in different months (October 87 *vs* November 88), as is the case here. Judging from 1987, with the exception of plot B, there was a general, slight increase in ground cover percentages from October to November by some 5%. After this, the cover area reduced to the initial value as the dry season developed in December and January. In the case of plot B, this further decreased the October value by 5%. Moreover, from table 6.2, it appears that in the early dry season, when most grasses begin to wither, the collective cover area of the grasses decreases generally in proportion to the increase in value of the non-grass species, specifically the

Table 7.2. Ground cover composition (% of cover area) in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988.

DATE	PLOT	GRASS	NON-GRASS		NOTE
			woody	herb	
29 Oct 1987	A	45	40	6	
	D	41	39	6	
	B	26	54	5	
	C	41	39	1	
27 Jan 1988	A	34	51	2	
	D	27	53	3	
	B	25	50	1	
	C	37	48	1	
27 Nov 1988	A	40	50	6	burned
	D	28	57	9	
	B	23	62	7	unburned
	C	34	60	5	
Differences Oct 1987 - Nov 1988	A	-5	+10	0	burned
	D	-13	+18	+3	
	B	-3	+8	+2	unburned
	C	-7	+21	+4	

woody plants, which continued to grow in November and December after late rains (see Table 7.2: January 1988). Given these factors, the general increase in the non-grass cover percentage in November 1988 as compared to October 1987 must be interpreted with care.

An absence of fire, or low fireline intensities, are commonly known to promote herbaceous and woody growth in many moist savannas (see Section 1.2.3.2). It is interesting, however, to note that the changes in vegetation composition in the trampled plot B were about equal to that of the low, head fire burn in plots A, with an 8-10% increase in the cover value of the woody growth, and a 3-5% decrease in the grass cover. But, given the differences between the months of October and November discussed above, this probably shows that plot A and B had closely maintained their original composition, with some increase in the woody species. Plot D and C, on the other hand, are more similar in their changes, with a significant incraese in the woody cover by some 20%, except that the decrease in grass cover in plot D (-13%) is more marked than in plot C (-7%). This

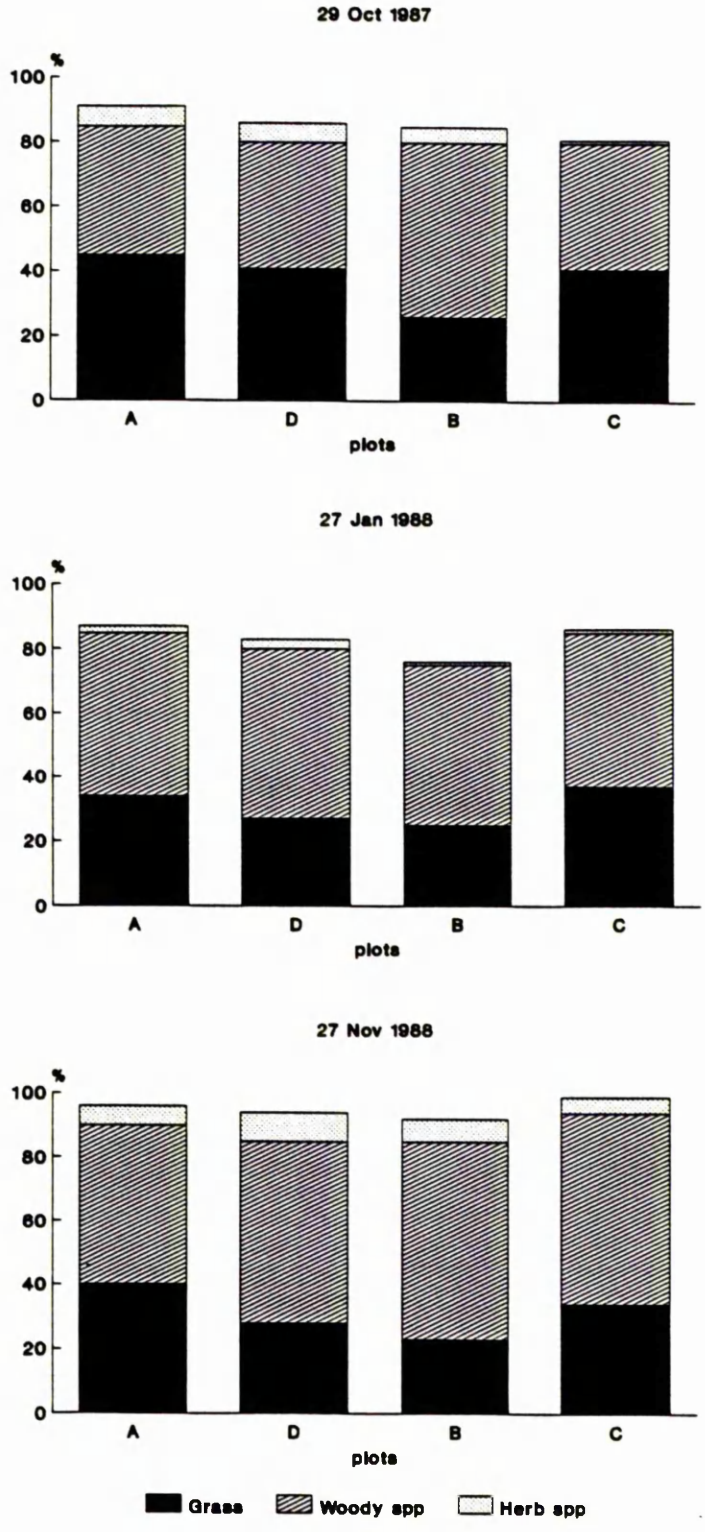


Figure 7.2. Composition of ground cover species in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988.

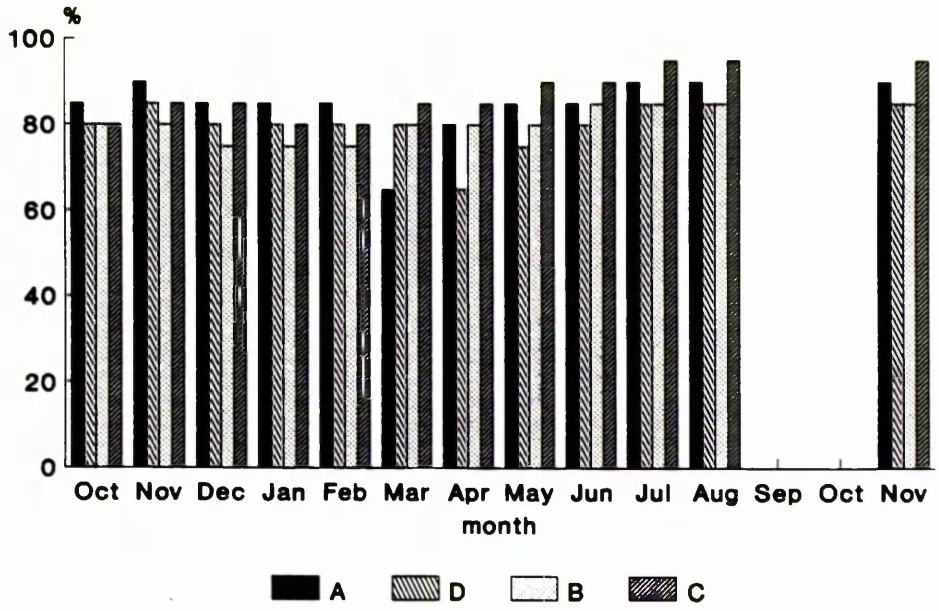


Figure 7.3. Total ground cover (%) in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988.

PLOT	MONTH													DIFF N'87 - 88
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	
A	85	90	85	85	85	65	80	85	85	90	90			90	0
D	80	85	80	80	80	80	65	75	80	85	85			85	0
B	80	80	75	75	75	80	80	80	85	85	85			85	+5
C	80	85	85	80	80	85	85	90	90	95	95			95	+10

Table 7.3. Total ground cover (%) of burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, 1987-1988.

is probably because plot D was burned when the moisture content of the ground cover was actually returning, rather than remaining dormant to dry up further, as would be the normal case in the late dry season. Hemicryptophytes, such as these perennial grasses, seem to be affected most. Perhaps this is partly to do with their growing buds being close to the ground surface where a low burning fire is at its hottest.

The slight increase (2-4%) in the herbaceous coverage in plots B, C and D are worth noting. Unlike other types of ground vegetation, the herbaceous element tends to be more extensive in the wetter months of September and October, especially the geophytes. Thus the increase in herbs in November 1988 is likely to indicate a higher herbaceous coverage also in the preceeding October (1988).

As for the overall ground cover, both burned plots recovered by November 1988 to the same value as November 1987. Meanwhile, the cover on the unburned plots exceeded their original value: the heavily trampled plot B by about 5%, and the little disturbed plot C by as much as 10%. This is much to be expected, with the 1988 rainy season being a particularly long and wet one.

7.3.2 Species diversity

Table 7.4 presents the number of ground cover species counted in October 1987, January 1988, and November 1988. For a 10 m^2 area, at the end of October 1987, the number of species ranged narrowly from 66 species in plot B, 64 in plot C, 62 in plot A, to 60 in plot D (mean = 63 spp). As the dry season developed, the species number fell by the end of January 1988 to an average of 50 species per plot (50 spp in A, 50 spp in B, 54 spp in C, 46 spp in D), with a noticeable disappearance of non-grass species, particularly the herbs (-8 spp in A, -7 spp in B, -8 spp in C, -5 spp in D). There were also decreases in the woody ground cover (-4 spp in A, -2 spp in C, -6 spp in D), but especially in plot B (-9 spp), where there had been heavy disturbance from elephants earlier on in the month. The number of grass species remained largely the same (7 spp in A, B, C), except in plot D, where almost half of the grass diversity had disappeared (-3 from 7 spp), most of which, however, were initially represented by only one or two specimens.

By the end of November 1988, there had been little increase in the number of woody species since the dry season. Thus, when compared with the count in October 1987, the number of woody plants at the end of November 1988 had been reduced by 4 species in plot A, 5 species in plot D, and by as many as 7 species in plot B, where there had been a further

Table 7.4: Number of ground cover species in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988.

DATE	PLOT	GRASS	NON-GRASS		TOTAL	NOTE
			woody	herb		
Oct 1987	A	7	42	13	62	
	D	7	43	10	60	
	B	7	49	10	66	
	C	7	43	14	64	
Jan 1988	A	7	38	5	50	
	D	4	37	5	46	
	B	7	40	3	50	
	C	7	41	6	54	
Nov 1988	A	8	38	17	63	burned
	D	5	38	18	61	
	B	8	42	14	64	unburned
	C	8	44	15	67	
Diff O'87 - N'88	A	+1	-4	+4	+1	burned
	D	-2	-5	+8	+1	
	B	+1	-7	+4	-2	unburned
	C	+1	+1	+1	+3	

heavy disturbance from elephants and gaur in April 1988. The least disturbed plot C, however, appears to be an exception, for there was no reduction in the number of woody plant species. However, in relation to fire, the relative stability in plot C is an illusion if the differences in species numbers is considered from January 1988, prior to the burns in plot A and D (0 spp in A, +2 spp in B, +3 spp in C, +1 spp in D). From then to November 1988, all four plots more or less maintained their woody species diversity. It thus appears that the number of woody species lost in the early dry season, between the October 1987 and January 1988 counts, was largely due to other factors, such as drought, grazing, or natural competition.

The herbaceous element is mostly seasonal and is naturally more abundant during the rainy season, especially towards its end, in the months of September and October, when I have noticed geophytes to be particularly plentiful, both at Khao Nang Rum and elsewhere. By November, some herbaceous species have begun to wither, depending on the termination

date of the Southwest monsoon. In these plots, a comparison between October 1987 and November 1988 shows some increases in 1988 in the number of herbaceous species, least of all, however, in plot C (+1 sp.), and most of all in plot D (+8 spp). This suggests that some small degree of disturbance, such as a burn with a low fireline intensity and/or trampling, can encourage herbaceous growth through gap creation, although this observation is by no means conclusive.

By November 1988, there was one additional grass species in each plot, including plot D, which had previously lost 3 grass species at the beginning of the dry season prior to the burn. All in all, the number of species of ground cover plants was well-maintained in all plots (differences between October 1987 - November 1988: +1 sp in A, -2 in B, +3 in C, +1 in D). Any slight increase or decrease by a few species is probably insignificant overall. Further more, in most cases, it is difficult to pin-point a particular variable as a responsible factor in the changing diversity of a given ground vegetation type. Plants in all plots are subjected to some degree of grazing and browsing, drought, natural competition between taxa and individuals, and in the case of plots A and D, low fireline intensity burns. Taking the least disturbed plot C, for example, from January 1988, 7 species of woody plants have disappeared, while 7 new ones have replaced them. This helps to emphasize the complexity of the plant population dynamics even without 'outside' stresses, such as disturbance from relatively heavy trampling and fire.

What may be concluded here, however, is that in the very short term, low fireline intensity burns (plots A and D) do not alter significantly the species diversity of the ground cover.

7.3.3 Dominance of ground cover species

Table 7.5 shows the number of ground cover vegetation species according to their cover value, counted and estimated in October 1987, January 1988 and November 1988. These are divided into those with a coverage of $\geq$5-25%; those with less than 5% cover; and those species with only one single specimen. No table on species distribution pattern is given, because, except for the single plants, all species were scattered in small clumps or individuals. Table 7.6 further lists the names of the species with a coverage of $\geq$5-25%, which are considered here to be the dominant ground cover species. The full list of all ground cover species in each plot at different periods of counting are given in Appendix I.

There is no marked trend concerning the dominance of ground cover species in relation to fire. The differences in the number of

species in each category of cover area between October 1987 and November 1988 are negligible, except, perhaps, for a slight increase in the number of single plants in plot A (+5 spp), and the noticeable increase in the cover area of the grass *Sorghum nitidum*, by as much as 7%. The reason for this spectacular increase is not known.

One odd pattern occurs in this set of data. This concerns the cover area of dominant species at the end of January 1988. While the cover area in some species increased or decreased slightly in other plots since October 1987 (see Table 7.6), most dominant species in plot C showed some marked increases in January 1988, particularly the grass *Apluda mutica* (+7%). There was also an increase in the number of dominant species in this plot (+3 spp), as the cover values of some species increased to 5% or more. Perhaps the only sensible explanation for this phenomenon is that since October 1987, the Southwest monsoon continued to fall and thus the ground cover continued to grow. This helped to increase the cover values of some species in all plots. But as the dry season advanced and large grazers visited the site, the cover area of some species reduced slightly.

DATE	PLOT	≥5%	<5%	1 plant	TOTAL	NOTE
Oct 1987	A	7	47	8	62	
	D	6	37	17	60	
	B	5	49	12	66	
	C	5	46	13	64	
Jan 1988	A	6	36	8	50	
	D	6	30	10	46	
	B	5	38	7	50	
	C	8	35	11	54	
Nov 1988	A	6	44	13	63	burned
	D	7	40	14	61	
	B	4	48	12	64	unburned
	C	5	47	15	67	
Diff O'87 - N'88	A	-1	-3	+5	+1	burned
	D	+1	+3	-3	+1	
	B	-1	-1	0	-2	unburned
	C	0	+1	+2	+3	

Table 7.5: Number of species by cover value (%) in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988.

SPECIES	OCT'87				JAN'88				NOV'88				DIFF 87-88			
	A	D	B	C	A	D	B	C	A	D	B	C	A	D	B	C
GRASSES																
Apluda mutica	8	20	5	17	8	15	6	25	7	18	5	17	-1	-2	0	0
Heteropogon triticeus	9	8		8	7	6		7	7	5		5	-2	-3		-3
Sorghum nitidum	12	8	6	6	15	5	8	10	19	7	6	5	+7	-1	0	-1
Imperata cylindrica	8		6		15		7		8		5		0		-1	
Coelorachis mollicoma				5				5								
SHRUBS																
Flemingia sp.		7	15	6		5	6	8	6	5	9	8		-2	-6	+2
Erythroxylum cambodianum	6		5		6		6	7	5	5			-1			
Helicteres sp	7															
SEEDLINGS																
Shorea obtusa	5	8			7	7				6				-2		
Dipterocarpus tuberculatus		8				6				6				-2		
Dillenia obovata								5								
Glochidion sp								5				5				
Total cover area of dominant spp	55	59	37	42	58	44	33	72	52	52	25	40	-3	-7	-12	-2

Table 7.6. Cover percentage of dominant ground vegetation, i.e. species with a cover area ≥5 %, in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988.

Thus, some decreases occurred in plots A, B and D. But, because plot C was situated in the middle (see Fig.4.6), sandwiched between plots A and D, it was most protected from the approaching herbivores. Therefore, the cover area increases of many species at the end of the rain were less hindered in this plot.

7.3.4 Ground cover height

Table 7.7 presents the monthly measured height of ground cover in three categories: grasses, seedlings, and other non-grass species, where only the dominant species of each category were selected. In the case of non-grass-non-seedlings, these are shrub species. Graphic presentations of these measurements are given in Figs 7.4a, b and c.

The methods of measurement and sampling have already been fully described in Chapter 4. However, a further note on seedling measurement needs to be added here. At the beginning of the field work, in October and November 1987, 10 seedlings per each species were not individually tagged to be measured as was the case from December 1987. Instead, they were measured randomly by 10 specimens/sp., including the tallest and the shortest plants, in a similar method employed for the measurement of the other ground cover categories. The method was later changed for the measurement of seedlings because it was considered to be more suitable for the purpose of the accurate follow up of seedling recovery after fire. Yet, the changes should not greatly affect the comparisons between the mean values derived from either methods of sampling, because the available number of each dominant seedling species was limited to around 10-12 individuals per plot, which happened to be the sampling

TYPE		MONTHS												DIFF N'87
		O	N	D	J	F	M	A	M	J	J	A	N	-88
Grass	A	98	130	152	117	83	37	52	76	83	96	103	128	-2
	D	88	125	154	111	72	66	30	61	71	81	89	153	+28
	B	93	109	117	95	79	74	30	82	87	99	107	114	+5
	C	103	151	180	126	92	91	78	82	94	119	125	147	-4
Seed-	A	33	38	42	41	40	20	30	41	44	45	48	45	+7
lings	D	40	35	38	37	37	40	19	30	33	37	38	33	-2
	B	38	35	36	35	37	40	19	48	49	51	52	52	+17
	C	33	39	42	39	37	41	46	52	52	54	55	52	+13
Other	A	40	43	46	44	42	20	30	41	44	45	48	45	+2
non-	D	46	43	46	46	44	44	22	38	44	50	54	50	+7
grass spp	B	45	44	44	44	44	49	22	54	57	63	64	61	+17
	C	48	52	54	50	49	55	60	66	69	74	78	76	+24

Table 7.7. Height of ground cover (cm) in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988. (Site inaccessible during September - October 1988 due to flooding).

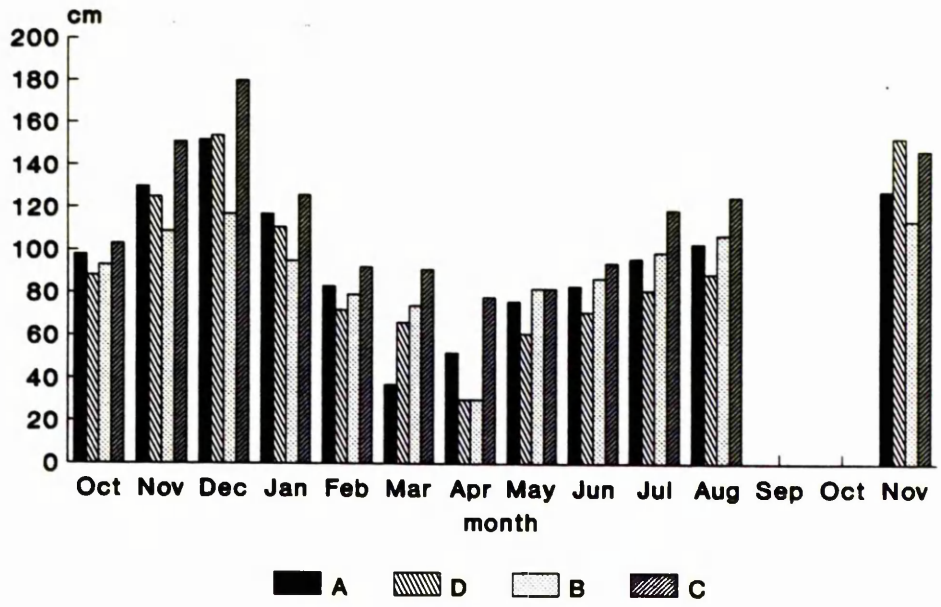


Figure 7.4a. Height of grass in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988. (Site inaccessible during September - October 1988 due to flooding).

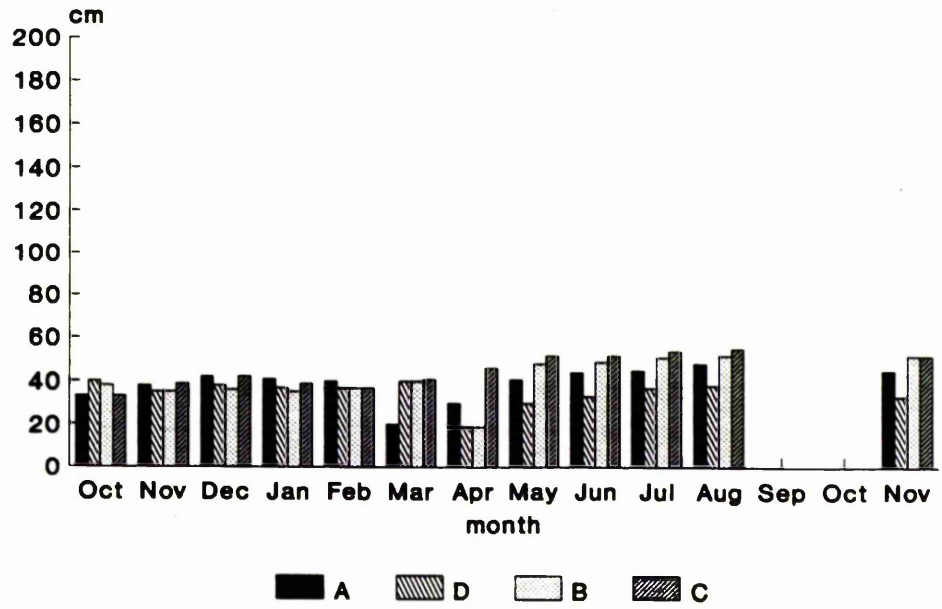


Figure 7.4b. Height of seedlings in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988. (Site inaccessible during September - October 1988 due to flooding).

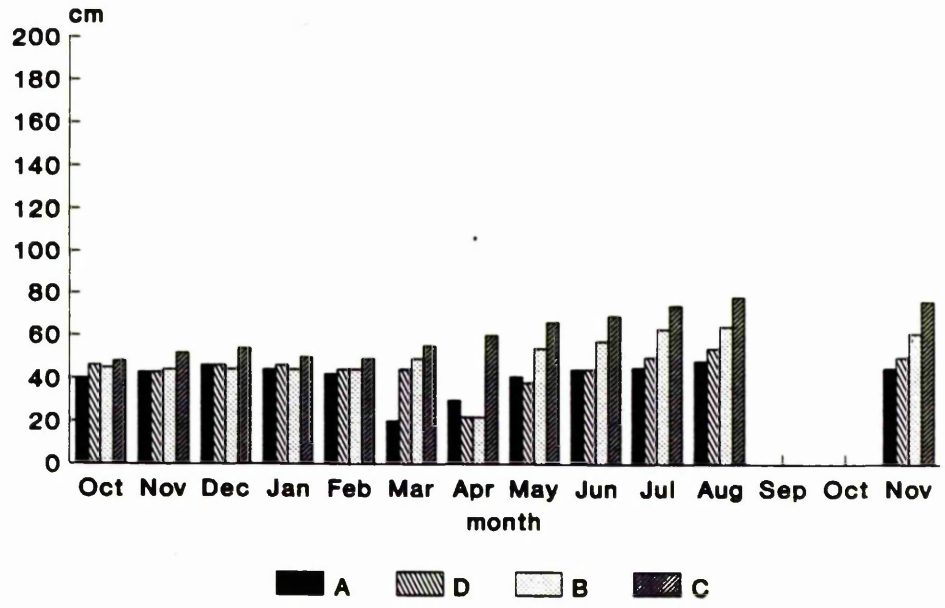


Figure 7.4c. Height of non-grass/non-seedling ground cover species in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988. (Site inaccessible during September - October 1988 due to flooding).

number chosen in both methods. The mean height of these seedling species is given by the month in Table 7.8, and graphic illustrations of those species found commonly in most plots are given in Figs 7.5a, b, c and d.

As ground vegetation was constantly grazed and browsed by herbivores, and some individuals sometimes died back naturally, even in the rainy season, their heights tended to fluctuate slightly over the year. Some patterns are, nonetheless, apparent. The grasses grew steadily during the rainy season at a mean rate of 10 cm $month^{-1}$ (excluding April and May), but the fastest growth occurred at two main periods. One was at the end of the rainy season and the beginning of the dry season, in November and December, when most grass species were flowering. Mean growth rate in November was 33 cm (range = 16-48 cm) and in December it was 22 cm (range = 8-29 cm).

After then the grasses began to wither and some would collapse until the arrival of the Southwest monsoon (see Table 5.10). It was during the first two months of this rain, in April and May, or more accurately, the first few months after any disturbances, that witnessed the other

period of fast growth rates. Plot A was burned on 24 February, and by the end of March, the mean height of the grasses reached 37 cm. They continued to grow rapidly during April and May, by a further 15 cm and 24 cm respectively. Similarly, by the end of April, one month after plot D was burned on 25 March, and a few weeks after plot B was heavily disturbed by elephants and gaur, the mean grass height in both plots reached 30 cm. By the end of May, the grasses grew further by +31 cm in plot D, and by as much as +52 cm in plot B. April also saw a remarkable growth of grasses in plot C, which attained 78 cm. However, the new grasses here had began to reshoot since March, but in that month, no records of new shoots were kept seperately from the existing ones. The actual rate of new growth cannot thus be ascertained.

The non-grass-non-seedling ground cover, or the shrubs, also grew steadily with a mean rate of 4 cm $month^{-1}$ during the rainy season, with the exception of April and May, when their growth rate was fastest. And as in the case of the grasses, they grew quickly in the first few months after disturbances. By the end of March, the dominant shrubs in plot A reached 20 cm just one month after the burn. In April and May, they grew an additional +10 cm and +11 cm respectively. As in plot A, the plants in plots D and B both reached the mean of 22 cm high in April, one month after disturbances. And in the following month, they continued to grow further by +16 cm in plot D, and by as much as +32 cm in plot B. Comparatively, growth rates at 5-6 cm $month^{-1}$ in the least disturbed plot C were not so spectacular during this period.

Seedlings behaved in much the same way. The mean growth rate during the rainy season months from June onward was 2 cm $month^{-1}$. Mean seedling height reached 19-20 cm one month after disturbances in plots A, B and D. Plot A seedlings continued to grow rapidly in April and May by an additional 10-11 cm $month^{-1}$. Likewise, plants in plot D grew further by +11 cm in May, but in plot B, they again grew by a remarkable +29 cm. This exceptional recovery of plot B ground cover in all categories in the second month after disturbances probably shows the difference in early recovery rates between trampled land (plot B) and burned areas (plots A & D). Growth rates in plot C during April and May were much lower than the rest, at 5-6 cm $month^{-1}$.

The differences in grass heights between November 1987 and November 1988 were slight, except in plot D where an increase of +28 cm was evident. The reason for this is not known. However, in the case of seedlings and shrubs, growth heights on unburned plots were noticeably better than on the burned ones. But even then, recovery was good in plots

Table 7.8. Seedlings height (cm) in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988.

SPECIES	PLOT	MONTHS												DIFF N'87 -88
		O	N	D	J	F	M	A	M	J	J	A	N	
Cratoxylum pruniflorum	A													
	D													
	B	56	40	48	51	54	55	61	62	64	65	64	82	+42
	C													
Dillenia obovata	A	35	32	29	28	29	14	26	41	42	46	45	44	+12
	D	23	22	19	19	19	21	12	32	35	39	40	32	+10
	B	25	22	24	23	27	26	35	35	38	39	39	39	+17
	C	22	23	24	24	24	26	32	42	39	38	38	45	+22
Dipterocarpus tuberculatus	A													
	D	31	30	29	29	30	37	17	19	19	23	23	21	-9
	B													
	C													
Glochidion sp	A	21	31	32	28	25	12	21	30	29	29	31	32	+1
	D													
	B	29	39	37	33	34	39	43	48	47	52	54	41	+2
	C	29	49	48	45	42	45	51	60	65	68	71	61	+12
Shorea obtusa	A	44	53	47	45	43	45	45	48	48	50	51	44	-9
	D	47	38	38	39	40	42	34	34	36	32	34	34	-4
	B													
	C	47	44	54	47	47	50	54	54	51	56	56	49	+5
Vitex limonifolia	A	47	57	63	63	62	8	28	45	55	56	64	62	+5
	D	58	51	65	60	60	61	15	36	42	54	56	47	-4
	B	41	37	35	35	32	40	42	47	48	48	51	46	+9
	C													

Flooding made this site inaccessible during September & October 1988

A and D, with some increase in height in most cases.

In the case of shrubs, height increases occurred in all plots, ranging from +24 cm in plot C, +17 cm in plot B, +7 cm in plot D, but only +2 cm in plot A. Seedlings appeared to do best in plot B, partly due to the abundant occurrence of *Cratoxylum pruniflorum*, which tended to be taller than other seedling species. Here, mean seedling height increased by +17 cm, while in plot C they grew by +13 cm and plot A by +7 cm. Seedling height in plot D was more or less maintained, with a slight

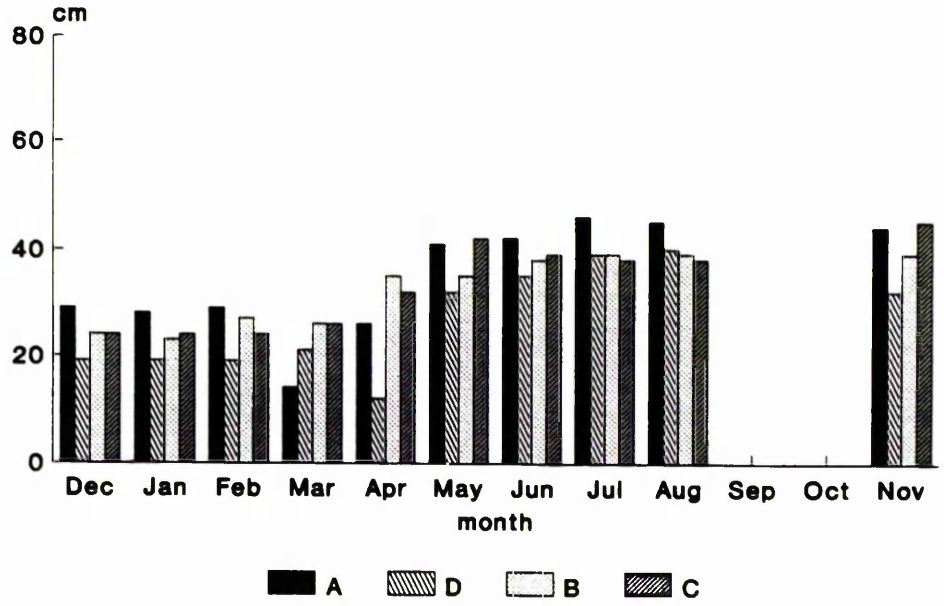


Figure 7.5a. Height of *Dillenia obovata* seedlings in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988. (Site inaccessible during September - October 1988 due to flooding).

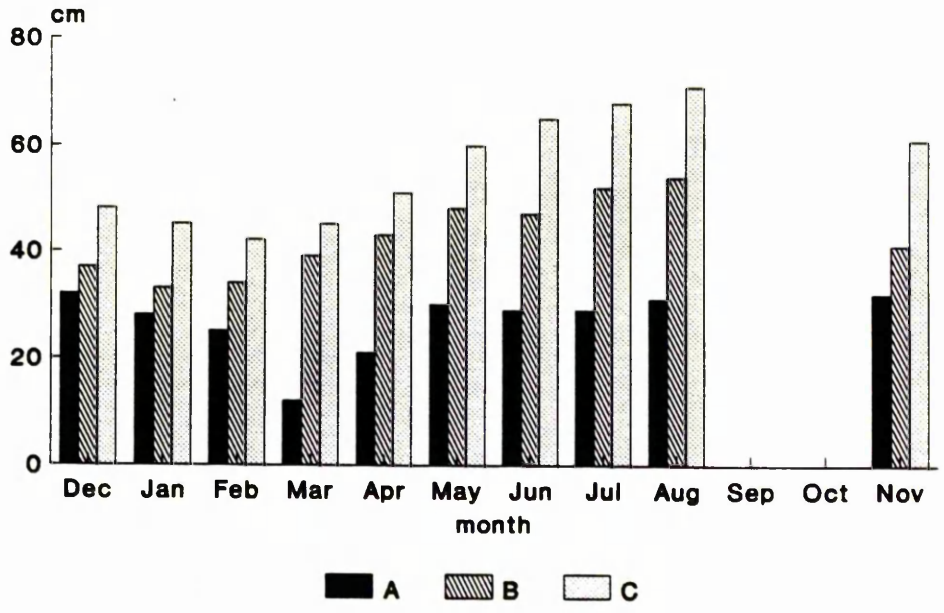


Figure 7.5b. Height of *Glochidion* seedlings in burned (A) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988. (Site inaccessible during September - October 1988 due to flooding).

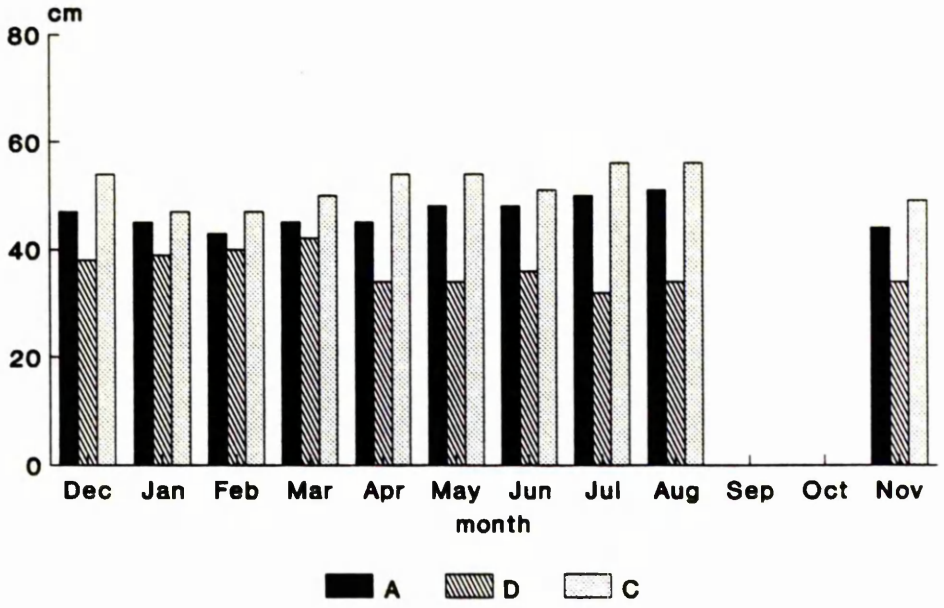


Figure 7.5c. Height of *Shorea obtusa* seedlings in burned (A, D) and unburned (C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988. (Site inaccessible during September - October 1988 due to flooding).

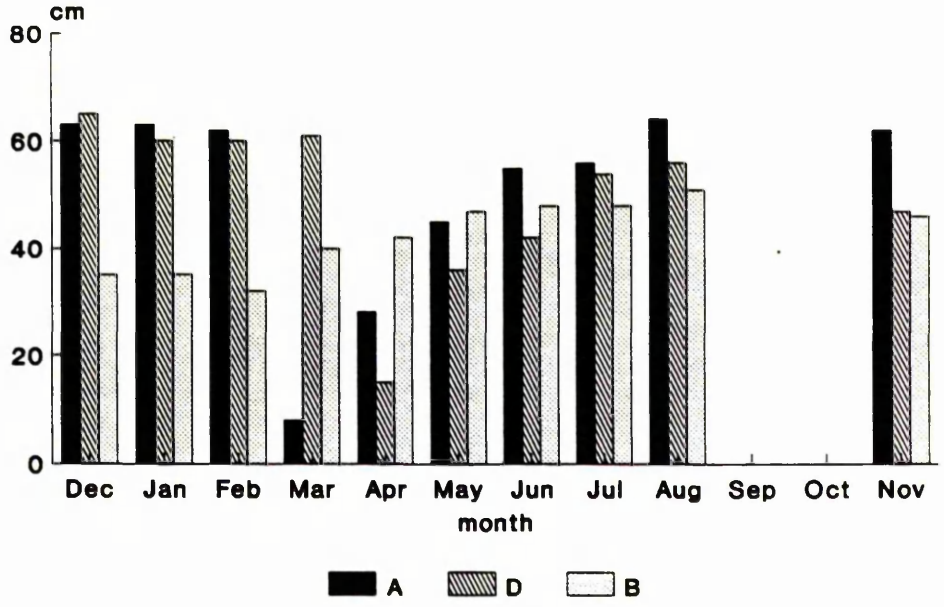


Figure 7.5d. Height of *Vitex limonifolia* seedlings in burned (A, D) and unburned (B) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988. (Site inaccessible during September - October 1988 due to flooding).

decrease of -2 cm. This decrease was probably due to browsing during the rainy season, for the August 1988 measurement was 5 cm higher than in the following November.

Table 7.8 gives the height measurements of selected seedling species in each plot. *Dillenia obovata* was the only species common in all plots. It also grew more than other species during the year, with the exception of *Cratoxylum pruniflorum* which had no comparison among different plots, as the latter only occurred abundantly in plot B (increase by +42 cm). In the burned plots A and D, *D.obovata* grew 10-12 cm higher than in the previous year. In plot B, its height increased by +17 cm, and in the least disturbed plot C by as much as +22 cm. A *Glochidion* sp. more or less maintained its height both in the burned plot A and the trampled plot B, while, again, it grew rather better in plot C (+12 cm).

In contrast to the above species, in November 1988, *Shorea obtusa* actually gained less height on the burned plots than it did in November 1987, with a decrease by -9 cm in plot A and -4 cm in plot D. Although these decreases were probably partly due to browsing, *S.obtusa* in plot C, which had also shown evidence of being browsed, increased its mean height by +5 cm. This, however, does not indicate that the slow-growing *S.obtusa* is less adapted to fire than the other species. In fact, its recovery after the burns had been the most remarkable of all. One month after fire in plot A, *S.obtusa* sprouted back to gain an even greater height (mean = 45 cm) than it had prior to the burn (mean = 43 cm). Indeed, one 19 cm tall individual died back to shoot up as high as 40 cm in the following month. In plot D, *S.obtusa* nearly attained its former height (mean = 42 cm) as it reached the mean of 34 cm one month after the fire.

Like other species, *Vitex limonifolia* samples in the unburned plot B gained more height (+9 cm) than those in burned plots (no samples in plot C). And since August, the plants in plot A had lost less height than those in plot D, probably through browsing. Thus, during the course of the year, *V.limonifolia* in plot A increased in height by +5 cm while in plot D it decreased by -4 cm.

It is apparent therefore that, while the height of all woody plant species in all plots fluctuated through some browsing and natural deaths, samples in unburned plots grew noticeably higher than in the burned ones. Nevertheless, the low fireline intensity burns did not retard woody growth very much, for their recovery on burned plots was

good, with growth generally as high, or higher than, in the previous year. *Dillenia obovata* seedlings did particularly well in all plots. Grass heights were generally maintained throughout.

7.3.5 Leaf litter depth and cover

In a deciduous forest, the recovering ground vegetation, especially the grasses, plays another role: it serves as a potential fuel source for the approaching dry season. To appreciate this role fully, therefore, the recovery of another fuel source must also be addressed, namely that of the leaf litter. This is often the most important source of fuel, particularly able to sustain an early burn in an area where the grass cover is not continuous, or when the grasses are not yet sufficiently dried (see Chapter 6).

Table 7.9 shows the monthly record of leaf litter cover percentage, and Table 7.10 presents the leaf litter depth accumulated in each plot. By the end of the dry season, leaf litter in both unburned plots covered as much as 95% of the forest floor and was up to 5 leaves deep. But, as the Southwest monsoon fell, the moisture and the impact of the rain broke up some of the leaf litter. Plot B tended to get trampled most by large herbivores, and this action also broke up the accummulated litter further. Thus, by November 1988, leaf litter cover in plot C still remained as high as 95%, at 4 leaves deep, while in plot B the cover was reduced to 50%, but also at 4 leaves deep.

Plot A was burned at the end of February, one month before plot D, when leaf litter covered 90% of the forest floor at 3 leaves deep. As trees were still shedding leaves (see Phenology, Fig.7.6), by the end of March, the new leaf litter covered as much as 75% at 2 leaves deep. The litter continued to build up to 80%, at 2 leaves deep by the end of April. As the rainy season progressed, however, the litter cover was reduced to 40%, and, by the end of November 1988, only 10% cover was left at just 1 leaf deep. The remaining leaves then became small broken matter, or fines.

Plot D was burned at the end of March, almost two weeks before the arrival of the Southwest monsoon, when leaf litter cover was 95% at 4 leaves deep. The following month thus found only 10% litter cover at 1 leaf deep. By the end of November 1988, only 5% cover remained.

So, although leaf litter provides a rich source of broken organic matter, it also represents potential tinder. In Chapter 6, it was shown that a well-sustained fire needs to burn on litter which is at least 2-3 leaves deep and probably with at least 70% litter coverage. This means

Table 7.9. Leaf litter cover (%) in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988.

PLOT	MONTHS														DIFF N'87
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	-88
A	25	30	35	80	90	75	80	40	40	40	40			10	-20
D	40	40	40	85	90	95	10	10	10	10	10			5	-35
B	25	35	35	85	90	95	95	95	95	95	95			50	+15
C	35	40	40	75	80	95	95	95	95	95	95			95	+55

Table 7.10. Leaf litter depth in burned (A, D) and unburned (B, C) plots, *Dipterocarpus* 1 stand, October 1987 - November 1988.

PLOT	MONTHS														DIFF N'87
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	-88
A	1	2	2	2	3	2	2	2	2	1	1			1	-1
D	1	2	2	2	3	4	1	1	1	1	1			1	-1
B	1	1	2	3	3	5	5	5	5	5	5			4	+3
C	1	2	2	2	3	5	5	5	5	5	5			4	+2

that, in the approaching dry season, plot C could potentially be burned as soon as the leaf litter was dry enough, perhaps in January. By this time, plot B would probably have accummulated enough leaf litter for a successful burn. If neither gets burned again, or if they are burned late in this second dry season, the accummulated leaf litter will be at least 8 leaves deep, which is a quantity that produces extreme leaf litter burns (Stott 1984).

Comparison between November 1987 and November 1988 shows that plots A and D had less litter coverage, by -20% and -35% respectively. This implies that neither plot could sustain a burn until late in the dry season. And as their burning potential was reduced from the previous year, there is a possibility of these areas not being burned at all, particularly if it rains as much as it did in the 1988 dry season.

7.4 Phenology

Observations on phenology of the plants in the *Dipterocarpus* association are divided into studies of the ground vegetation and studies of the canopy trees. For the convenience of data presentation, the former is further divided into two sets. First there is the record of plant flowering and fruiting, and secondly, there are notes on leaf shedding and flushing, and the withering and re-appearance of new individuals.

7.4.1 Flowering and fruiting of the ground cover

Fig.7.6 shows the periods for flowering and fruiting of some key plant species. This is confined to grasses, sedges, other herbs, and some low shrubs only. Being normally too small in size for sexual reproduction, no tree seedling, and not many shrubs, flowered in the study year.

Six flowering and fruiting patterns were apparent:

1) Flowering and fruiting more or less simultaneously from early or mid-rainy season (from April/June) to early dry season (to November/January)

In this category, fruiting often occurred one or two months after flowering had begun, but largely the two activities were simultaneous. This pattern is common among several grass species (i.e. *Setaria pallide-fusca* (Schumach.) Stapf., *Panicum auritum* Presl.ex Craib., *Coelorachis mollicoma*), in all the members of the Cyperaceae, and in most low shrub species that flowered in the study year (e.g. *Flemingia* sp., *Leea indica*, *Helicteres* sp.). The shrubs *Erythroxylum cambodianum* and *Ardisia crenata* flowered and fruited almost throughout the year (April/May-February), except in March. These two shrub species could either be placed as extreme examples of this phenological pattern, or they might be better categorized seperately on their own.

Except for the geophytes *Murdannia* sp., and perhaps *Globba leucantha*, this flowering-fruiting pattern is unusual among the herbaceous growth, except in the Cyperaceae.

2) Flowering during the rainy season (from May), fruiting at the end of the rainy season or in the early dry season (from October-January)

This pattern is similar to the previous one, except that fruiting does not take place until the end of the Southwest monsoon, or after. It then ceases by the end of January. This is a rather common pattern among the geophytes (e.g. *Cyanotis barbata* D.Don., *Zingiber*

Figure 7.6. Periods of flowering and fruiting of selected ground cover species, *Dipterocarpus* 1 stand, October 1987 - November 1988.

GROUND COVER SPECIES	FAMILY	TYPE	FLOWERING AND FRUITING MONTHS Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
GRASSES			
Apluda mutica L.	GRAMINEAE	G	------=-=-=-=-=-
Coelorachis mollicoma (Hance.) Bor.	GRAMINEAE	G	----------=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-
Eulalia speciosa (Debeaux.) O.Kitze.	GRAMINEAE	G	1988
Heteropogon triticeus(R.Br.) Stapf.ex Craib	GRAMINEAE	G	------=-=-=-=-=-=-
Imperata cylindrica (L.) Beauv.	GRAMINEAE	G	A-A-A-A=A=A=
Panicum auritum Presl.ex Nees.	GRAMINEAE	G	----------=-=-=-=-=-=-
Saccolepis sp.	GRAMINEAE	G	1988
Setaria pallide-fusca (Schumach.) Stapf.	GRAMINEAE	G	----------=-=-=-=-=-=-=-=-=-
Sorghum nitidum Pers.	GRAMINEAE	G	------=-=-=-=-=-=-
unidentified sp.1	GRAMINEAE	G	
SEDGES			Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
Carex speciosa Ktze.	CYPERACEAE	H	------=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-
Cyperus cyperoides Ktze .	CYPERACEAE	H	------=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-

zerumbet, Globba obscura, Kaempferia pulchra Ridl.). *Thunbergia fragrans* Roxb., which was one of the few climbers that flowered, also exhibits this pattern.

3)Flowering and fruiting in the early dry season (from October/ November-January)

This is one of the most common patterns in the grasses, herbaceous growth, as well as in several low shrub species. Flowering in the herbs, however, may take place towards the end of the rainy season, from September or October, and precedes the fruiting period by a month or two. In all cases, fruiting ceases by the end of January, or the beginning of February at the latest.

The dominant grasses, namely, *Apluda mutica, Sorghum nitidum* and *Heteropogon triticeus* are in this group. *Eulalia speciosa* (Debeaux.) O.Kitze. and a *Sacciolepis* sp. flowered at the end of the study in November 1988 only, but it is likely that their phenological patterns may belong to this group. *Eupatorium odoratum, Elephantopus scaber* and *Desmodium motorium* (Houtt.) Merr. are a few of the many herbs that showed this pattern. Others include species whose flowers appeared only in November 1988, such as *Andrographis* sp., *Acanthac* sp., *Crotolaria* sp., *Desmodium alatum* D.C., as well as the geophytes *Costus speciosus* Smith and a *Chlorophytum* sp. On the other hand, relatively few shrubs showed this pattern, e.g. *Barleria cristata* L., *Pavonia rigida* Hochr. and *Moghania macrophylla* Ktze.

4) Flowering and fruiting during the rainy season

In this category, the flowering and fruiting periods were often brief. Many were noted only once. Thus this group may well include many non-grass species flowers or fruits of which were never seen at any formal check time at the end of each month. Key species are many geophytes, such as *Curcuma parviflora, Globba obscura, Kaempferia pulchra,* and the ground orchid *Habenaria linguella.* There were few woody plant species in this group, and only *Grewia abutilifolia* Vent.ex Juss. and an unidentified climber were noted.

5) Sporadic flowering and fruiting throughout the rainy season and the early dry season

Some species in this group, such as the shrub *Polyalthia debilis*, may in fact belong to group 1, and they only appear sporadic because fruits were few, and were often eaten by herbivores. On the other

hand, many species in group 4 may also belong to this group, but their flowers happened to be noted only once in the rainy season. Bearing these possibilities in mind, however, this group includes the shrub *Pluchea polygonata* and the herb *Hedyotis* sp.

6) Flowering and fruiting after fire or other disturbances

It cannot always be ascertained that the flowers which appeared one or two months after a fire were directly induced by the burn. However, there is nothing ambiguous in the case of the grass *Imperata cylindrica*, which was commonly found in all plots except plot D, but only flowered in plot A, one month after the burn. The same phenomenon was also observed elsewhere. Similarly, it is likely that the herb *Elephantopus scaber* could have been encouraged to flower by fire, as it flowered one month after burns in both plots A and D. This member of the Asteraceae (Compositae) family had already flowered once before in every plot in November and December at the beginning of the dry season.

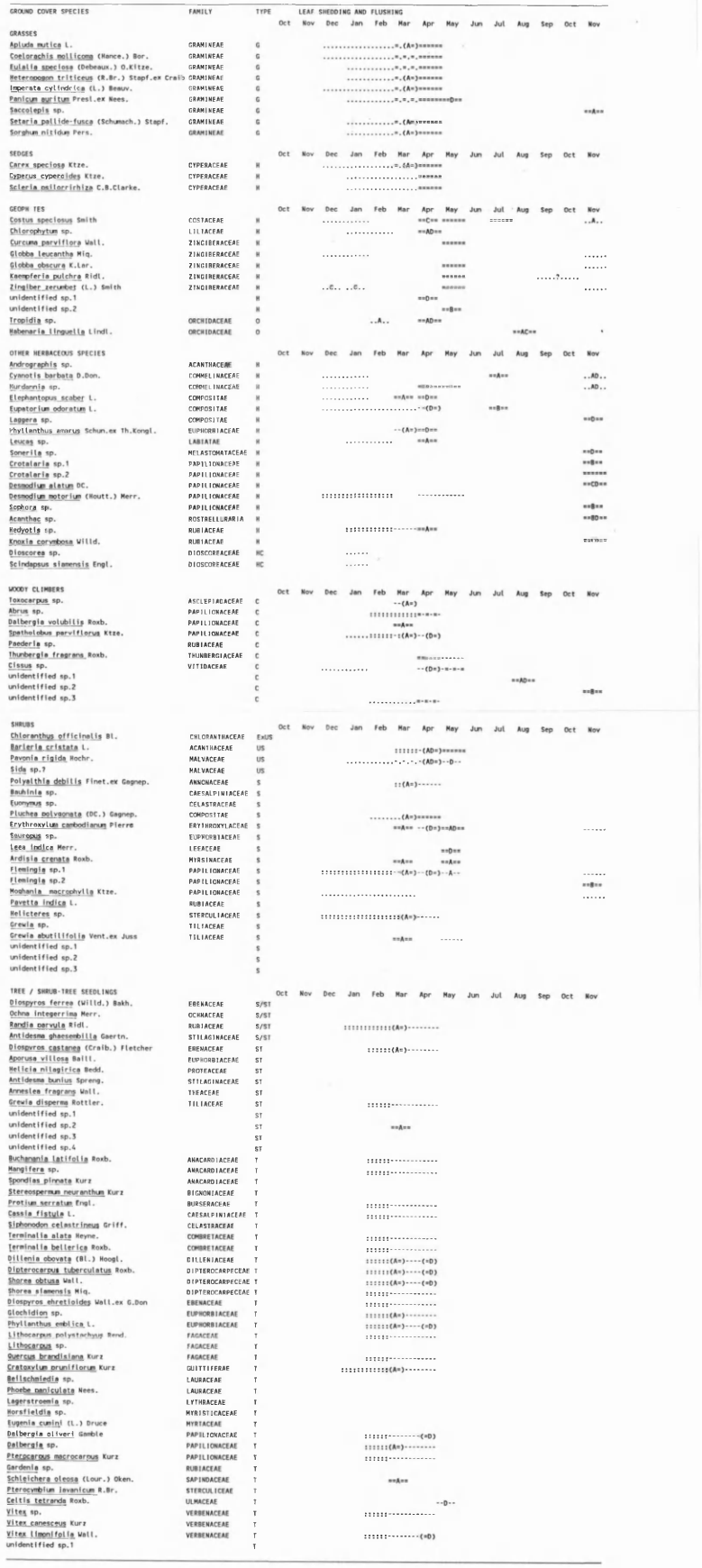
Flowering in a few geophyte species also appears to have been encouraged by the burns, such as a *Chlorophytum* sp., which flowered in both plots A and D, two months after the burn, having once flowered at the end of the preceeding December. Unfortunately, this *Chlorophytum* sp. did not occur in the unburned plots to provide a comparison. One unidentified geophyte also flowered a month after plot D was burned, and one flowered a month after plot B was heavily disturbed by large herbivores in April.

Elsewhere in the wildlife sanctuary, the geophyte, *Eurycles* sp., has been seen to sprout and flower gregariously towards the end of March, in an open dry dipterocarp forest, about 3 weeks after fire (Klaichoke, pers.comm.).

7.4.2 Leaf shedding and flushing of the ground cover

Fig.7.7 shows the time of leaf shedding and flushing, or the withering and re-appearing, of some important ground cover species in the experimental plots. Generally, plant withering, or leaf drying, began to occur after the last Southwest monsoon (29 November 1987) from December or January, while leaf shedding took place from January or February, and continued until around early or mid-March, when some new leaves then began to flush. Major periods of leaf flushing continued in April, with the return of the Southwest monsoon (6 April 1988). New plants, particularly the annuals, started to appear this month or shortly after burns in the dry season. Ground cover species were not counted in detail during the rainy season until the end of November 1988, when many new species were

Figure 7.7. Periods of leaf shedding, leaf flushing, withering, and appearance of selected ground cover species, *Dipterocarpus* 1 stand, October 1987 - November 1988.



recognized, particularly leguminous herbs belonging to the Papilionaceae.

This pattern varies slightly in detail among the different groups of ground cover as is described below:

1) Grasses (Gramineae)

The grasses began to wilt from December or January, until new blades generally pushed up in April, although some already started to appear in March. Young shoots, however, shot up soon after fire. Around the research station area, new grasses were found to appear from as early as 4 days to two weeks after a burn, probably depending on the available soil moisture content.

In the field, young *Eulalia speciosa* cannot be distinguished from the more dominant *Sorghum nitidum*. Thus, in Fig.7.7, a question mark is placed against the appearance of young *E.speciosa*, for its appearance at that time has to remain speculative.

2) Cyperaceae

This sedge family behaves like the grasses. But, except for *Carex speciosa* Ktze., the young plants were extremely difficult to identify, with a similar appearance to the young grasses *Eulalia speciosa* and *Sorghum nitidum*.

3) Geophytes and other herbs

Most herbaceous remains disappeared quickly after they wilted and died in December and January. Some perennial herbs, however, shed some leaves and flushed again in April or after a burn (e.g. *Hedyotis* sp., *Desmodium motorium*). Likewise, most herbs re-appeared at these times. It was also noted that a ground orchid, *Tropidia* sp., appeared in both burned plots A and D in April.

4) Woody species

Some young woody climbers or shrub specimens wilted and disappeared from December to January. Otherwise, many started to shed leaves from January and February. Few began leaf-shedding as early as December, such as a *Flemingia* sp. and a *Helicteres* sp. Meanwhile, other species remained largely evergreen, noticeably *Erythroxylum cambodianum* and *Ardisia crenata*, both of which flowered and fruited simultaneously almost throughout the year.

Most tree seedlings started shedding leaves in February, although a few began earlier in January (e.g. *Cratoxylum pruniflorum*).

Generally, however, this took place a few weeks later than in most canopy trees (see Fig.6.8). This probably indicates that the thinning canopy allowed more direct sunlight and a higher air temperature to reach the forest floor. Furthermore, seedlings appeared to shed less leaves, but many did shed leaves completely or almost completely (e.g. *Cratoxylum pruniflorum, Terminalia alata, Glochidion* sp.).

Leaf flushing occurred in March and April, while new plants appeared in April, or soon after burns.

7.4.3 Phenology of the canopy trees

Fig.7.8 presents the phenology of several canopy tree species, the litter from which was collected in sample baskets. The data is further supported by general observations. The trees chosen are the dominants, *Dipterocarpus tuberculatus* and *Shorea obtusa*; and species generally common in dry dipterocarp forest, namely, *Dillenia obovata, Terminalia alata*, and the shrub-tree *Randia parvula*. Other trees are *Quercus brandisiana*, which is not rare in mesic dry dipterocarp forest, and *Pterocarpus macrocarpus* Kurz, which is also characteristic of monsoon forest.

Most trees started shedding their leaves from the second week of January and these continued to shed until March, with the heaviest litter biomass in February (see also Table 5.5). And, as was the case with the woody ground cover, leaf flushing then occurred in March and April. This is also the time when some of the trees flowered (*Dipterocarpus tuberculatus* and *Quercus brandisiana* in March, *Dillenia obovata* in March & April, *Pterocarpus macrocarpus* in April & May). None of the other tree species flowered in the study year.

Fruiting took place in the same month, or closely after. This was followed by some two months of fruit fall in the case of *Dipterocarpus tuberculatus* (April & May), *Dillenia obovata* (May & June), and *Quercus brandisiana* (May & June). On the other hand, the period of fruit fall in *Pterocarpus macrocarpus* was lengthy, from around July all through to as late as February in the next year, although the main period of fruit fall was observed to be during August, September and October. Although *P.macrocarpus* drops its fruits before fire, it is unlikely that fire helps in the germination of this flammable 'space ship-shaped' winged fruit. In fact, this essentially monsoon forest tree seems to be less fire-tolerant, although it almost certainly be able to cope with a moderate level of fire. Most likely, a few escapees from a large number survive the fire pressure. It was noted that *P.macrocarpus* fruiting is particularly gregarious.

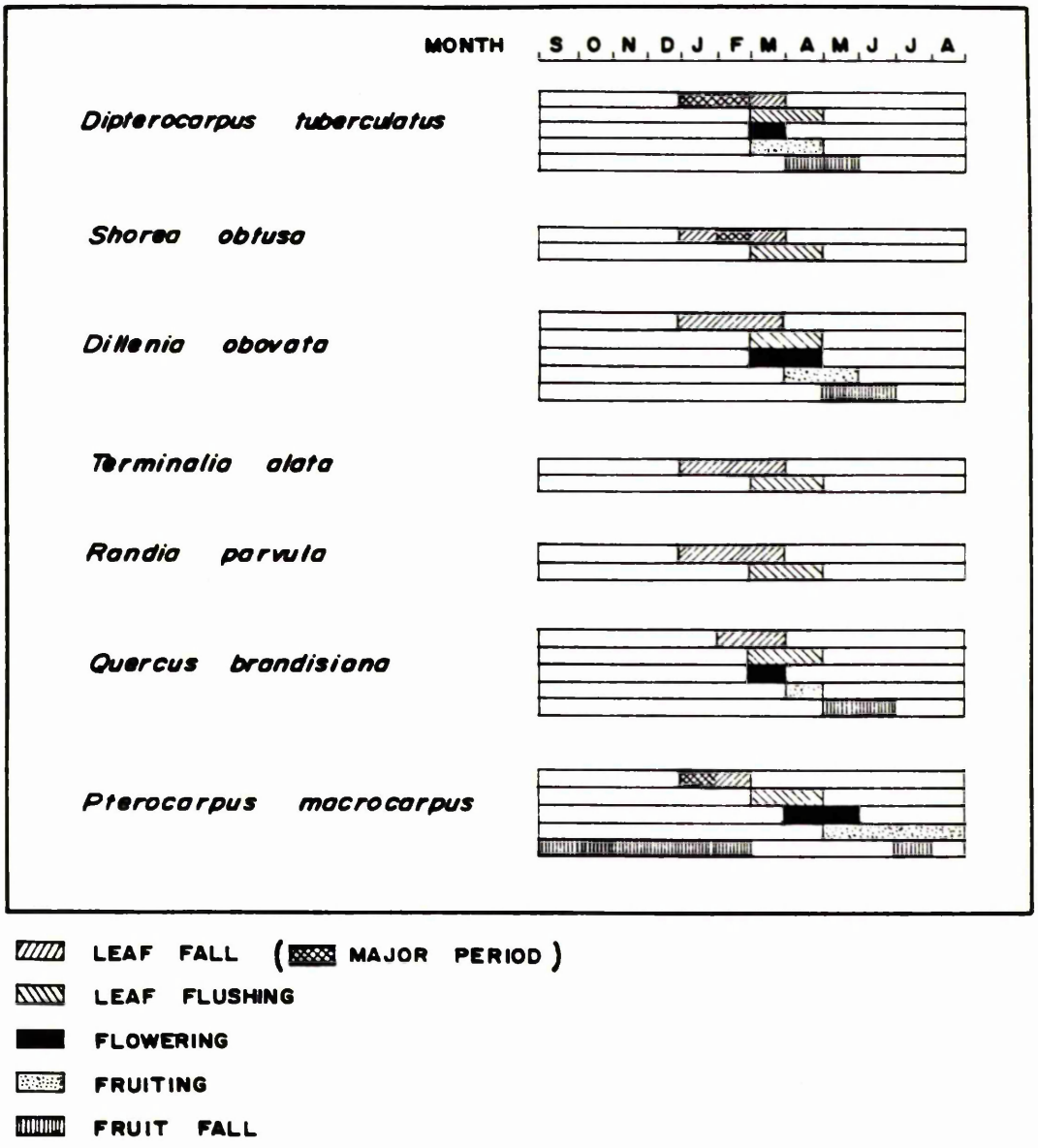


Figure 7.8. Phenology of some selected canopy trees, *Dipterocarpus* 1 stand, October 1987 - November 1988.

The other tree species, which are more common in the dry dipterocarp forest, drop fruits and germinate right after the fire season along with the early rains, when soluble nutrients are newly released by fire and are not yet leached away. Elsewhere, this has also been found to be the most common pattern for dry dipterocarp forest trees (e.g. Sukwong *et al* 1975, Santisuk 1988).

7.5 Conclusions

It was found that a high intensity fire, with a maximum temperature of >600°C, produces a complete ground cover burn, with only 20 cm high charred grass bases remaining. This type of burn is above all associated with the grass *Heteropogon triticeus*. The height of leaf browning and curling in this kind of burn can be from over 2 m to 10 m high. Seedlings and other non-grass species are completely charred, unless they grow beyond >1 m radius of the nearest burning grass clump, as was the case in burn No.1.

None of the burns on the permanent study plots in the *Dipterocarpus* association was a high temperature burn. This is unfortunate for the purposes of comparison, as these plots were observed regularly for vegetation recovery after the burns. In fact, both burned plots in this forest stand, namely, A and D, carried fires with the lowest fireline intensity of all the experiments. The dominant grasses burned here were a mixture of *Apluda mutica, Heteropogon triticeus,* and *Sorghum nitidum*. Ground cover with *A.mutica* tends to produce a low temperature burn, with a maximum temperature of <500°C. This grass species does not combust as well as the other grass species, and often leaves a very incomplete burn, with whole grass clumps remaining untouched.

However, as one of the control plots, B, was heavily trampled by elephants and gaur from time to time throughout the study year, this gave an opportunity to compare the changes in ground vegetation and fuel sources between burned plots under a low fireline intensity (A,D), a trampled plot (B), and a little disturbed plot (C). Furthermore, D was burned one month after A when the grasses and other ground cover were beginning to flush, less than two weeks before the arrival of the Southwest monsoon.

Thus, after one year of observation, it was found that overall ground cover area had increased in both unburned plots: plot C by +10% and the trampled plot B by just +5%. The ground cover area was maintained in the burned plots. The composition, however, had varied. In all the plots, there was an increase in the non-grass cover, particularly in C and D (+20%). At the same time, there was a general slight decrease in the grass cover, although the reduction was only significant in plot D (-13%). This reflects the trend observed in African moist savannas, where an absence of fire and a low intensity burn tends to encourage woody growth, while a fire burning when grasses are partially green, without most of their energy reserves stored underground, discourages grass growth. It was also found that, although a low fireline intensity tends to leave many

seedlings uncharred, most of these 'unburned' seedlings died several days later after the burn. A few seedlings out of ten samples survive, however. This is one of the reasons why a low fireline intensity promotes non-grass growth.

Despite some changes in ground cover composition, the actual species diversity of the ground vegetation was more or less maintained in all plots. Nevertheless, some small increases in non-grass herbaceous species were evident in the burned and trampled plots. Perhaps this shows that such disturbances may help to keep parts of the forest floor open for herbaceous growth, many of which are leguminous species. The cover area of each dominant species was also generally maintained, with little change in relation to fire or trampling. An exception to this was the grass *Sorghum nitidum* in plot A, which increased rather significantly (+7%) at the expense of slightly reduced cover areas in some other grass species. However, nothing can really be concluded from such a short period of study concerning the dynamics of species diversity and species dominance.

Recovery rates were fastest right after disturbances and during early rain in April and May. The fastest rate was generally seen in the trampled plot B, followed by both burned plots A and D. Plot C was the slowest, at least in the growth rate of woody ground cover. However, within the study year, woody species had generally gained most height in plot C, since the initial measurements. This was followed by plot B. And although the height gain was least in plots A and D, woody species had generally either grown taller, or had more or less maintained their mean heights, in both the burned plots. It was not evident that the few seedling specimens which survived fire had grown any higher than the dead ones, which resprouted so quickly that some were able to achieve a greater height than they had prior to the burn within the period of only one month. The seedling species which grew best in all the plots was *Dillenia obovata*.

The appearance and flowering of several ground cover species seemed to be induced or encouraged by the occurrence of fire. These include a few geophytes, such as a *Chlorophytum* sp. and the ground orchid, *Tropidia* sp., the herb *Elephantopus scaber*, but especially the flowering of the grass *Imperata cylindrica*. Most ground cover, however, fruits during the rainy season, and particularly, in the early dry season, from October to December or January, just before the beginning of the main fire season. This means that the seeds are likely to be able to withstand or to avoid fire, through burial for instance, with germination in April and

concurrent with the arrival of the Southwest monsoon. On the other hand, most canopy trees characteristic of dry dipterocarp forest that flowered in the study year, fruit in March and drop their fruits after fire to germinate on the nutrient-rich soil in April and May. The exception here is *Pterocarpus macrocarpus*, which drops its fruits before the fires. This species is more common in the monsoon forest, which is also a fire-prone formation, although little work on the ecology of fire has been done in this forest type.

Observation on the site phenology further showed that leaf shedding of the canopy trees generally starts in January, and usually precedes that of the deciduous woody ground cover by some 2-4 weeks, thus allowing more direct sunlight to reach the forest floor. The leaves continue to fall abundantly until around mid-March, when new leaves are beginning to flush. This means that an area burned in the early or mid dry season, as in plot A, would still be accumulating enough leaf litter to support another burn by the end of the dry season (>70%, 2 leaves deep). Nevertheless, by the end of the study year, most of this litter had been broken up into small matter (fines), partly by grazers trampling and partly by heavy rain. Thus both burned plots A and D were left with less leaf litter than they had originally in the previous year. In contrast, the leaf litter in plot C, which was the least disturbed, had accumulated to as much as 95% cover, at 4 leaves deep. Since leaf litter is an important tinder and fire sustaining fuel in this forest stand, this gives plot C a high potential for an early burn in the following dry season. In contrast, if the drought is not going to be unusually severe, a burn in plot A or D would not be possible until late in the dry season, or perhaps not at all. It is likely that the temporal and spatial pattern of leaf litter biomass may rotate burning time and/or frequency in some dry dipterocarp stands.

CHAPTER 8.

DISCUSSION

8.1 Introduction

This last chapter reviews, and then discusses, the results outlined in the preceding pages. The general contribution to the field of study, fire ecology in the tropical savanna forests, and the practical contribution towards fire management in the context of Thailand are both evaluated.

8.2 The results

8.2.1 Conditions for burns and fire occurrence

The main dry season in the study area generally begins in the cool of December and lasts until around early to mid-April, or even later, although a Northeast monsoon normally brings a small amount of rain in February. In 1988, the year of study, however, this Northeast monsoon was exceptionally heavy.

Fuel moisture content is one of the primary factors determining burn sustainability. Leaf litter is particularly important in this respect, being an essential tinder for early burns and for situations in which the grass fuel is only partially dry. In these experiments, the marginal moisture content to sustain a burn continuously was found to be less than 38% for most grass burns, and around 9% for leaf litter burns, although a leaf depth of three leaves or more seems to be crucial for carrying the burn at this moisture level.

Being closely related to the top-soil water regime, grass moisture content in the *Dipterocarpus* association was lowest in January and February, when it fell a little below the vital 38% level, but this association never sustained a burn well throughout the dry season. In the more open *Shorea* associations, however, grasses got much drier, mostly dropping below 38% from January to the end of March, with the lowest value occurring in February, at 17% in one stand. Consequently, burn sustainability in the relatively closed *Dipterocarpus* association depended most on the leaf litter, but was based on a wider range of fuels in the more open *Shorea* plots.

Leaf litter moisture content in the *Dipterocarpus* association was lowest in March at 1.5%, one month after the period exhibiting the thinnest canopy in February. This is a moisture level at which even a

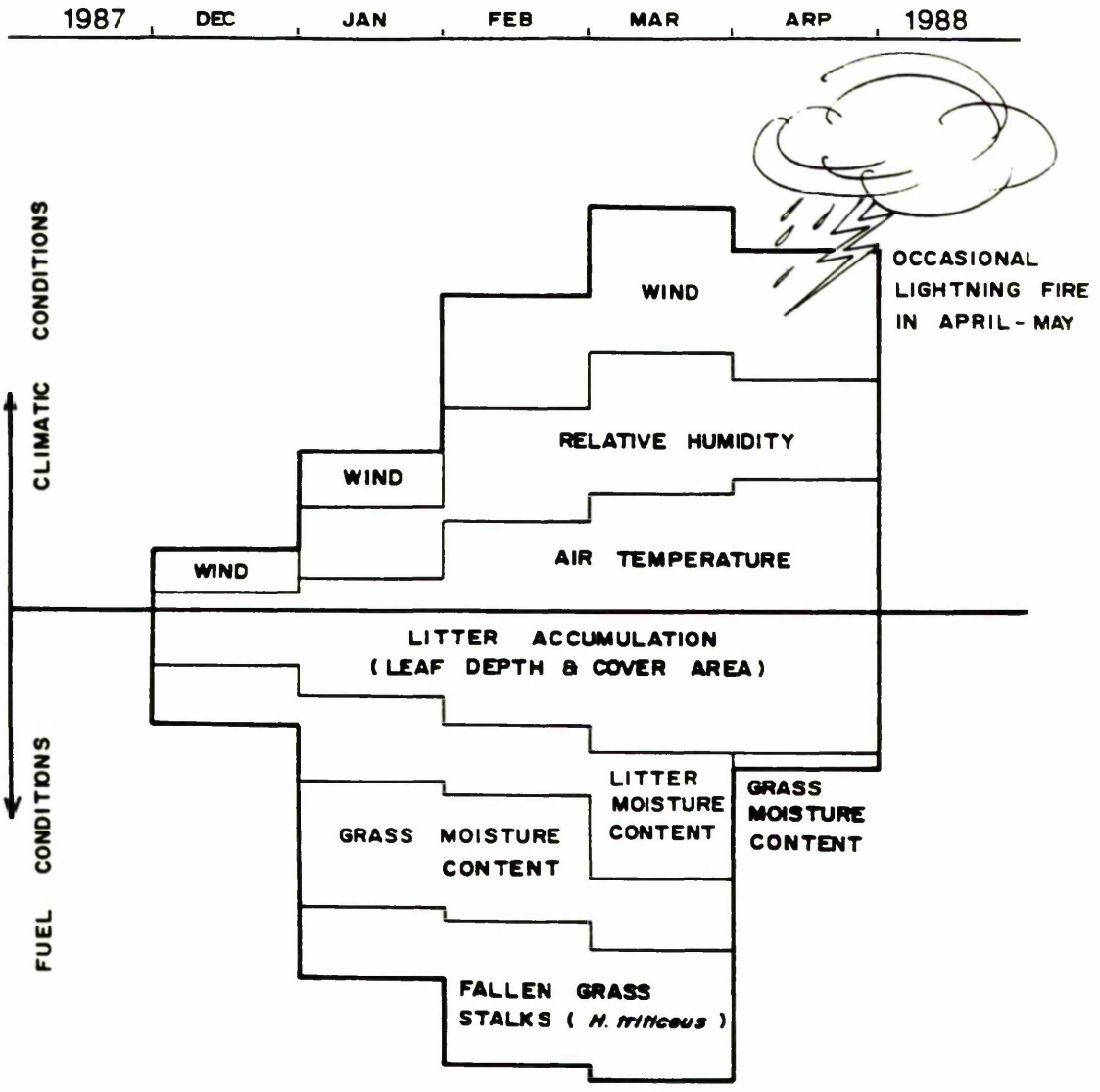


Figure 8.1. Conditions for burning during the dry season.

Based on a score of 1-10, values have been attributed to each variable in each month. The score is given according to the proportion of the value within a given range. For example, the temperature range in these months falls between 20-30°C. February, which has a mean temperature of 26°C, scores 6. For a variable where the decreasing value gives a more favourable condition for a burn, the score is accordingly given in reverse. For example, the relative humidity range falls between 58-68%. Mean humidity in the February is 60%, and it thus scores 8.

single leaf readily sustains fire. In addition, accumulation of leaf litter biomass is also greatest in March, following the period of considerable leaf-shedding from mid-January, through to the peak in March, by the end of which the forest floor is carpeted to at least five leaves deep. However, a leaf litter cover of $\geq$70% at 2-3 leaves deep is enough to sustain a burn, and this level of litter accumulation is generally attained by the end of January.

Once a burn is no longer inhibited by fuel moisture content, fire behaviour is much more influenced by air temperature and grass fuel arrangement, where a higher air temperature and fallen grasses yield higher fire temperatures and faster speeds of spread (see Fig.8.2). Loosely-packed collapsed grass stalks tend to provide better conditions for a burn by improving circulation of the heated oxygen, where there is enough space to allow sufficient amounts of oxygen to reach the zone of combustion, yet the grass is dense enough for efficient heat transfer.

Different grass species form different fuel arrangements as they lose moisture through the dry season. This is probably due to the variations in silica content. Among some of the dominant species studied, the stalks of *Apluda mutica* remained upright throughout, about half of the *Sorghum nitidum* stalks and most, or all, of the *Heteropogon triticeus* stalks collapsed, mainly after the rains of the Northeast monsoon in early February. All three species are important in the *Dipterocarpus* association, where the canopy is relatively closed and the grasses form 30-50% cover. In contrast, most of the *Shorea* associations studied are open, with a much lower diversity and lower proportion of non-grass and woody species, and these tend to be dominated by *H.triticeus*, which often comprises up to 60-90% of the ground cover. The importance of grass fuel arrangement is high, in that, in one early burn in January on half-trampled *H.triticeus* in a *Shorea* association, fire was maintained with a moisture content well above 38%.

Except for the Northeast monsoon in February, the fire climate improves steadily towards the hot season, with the optimum conditions for a burn occurring in March, when the wind velocity is at the highest throughout the year; air temperature is near its highest; and relative humidity is at its lowest. Thus fire occurrences, starting from the second week of January in 1988, peaked in March, when both climate and fuel coincided to produce ideal fire conditions (Fig.8.1). Indeed, fire did not occur at all in the more closed stands of any *Dipterocarpus* association and mixed dry dipterocarp forest until this time.

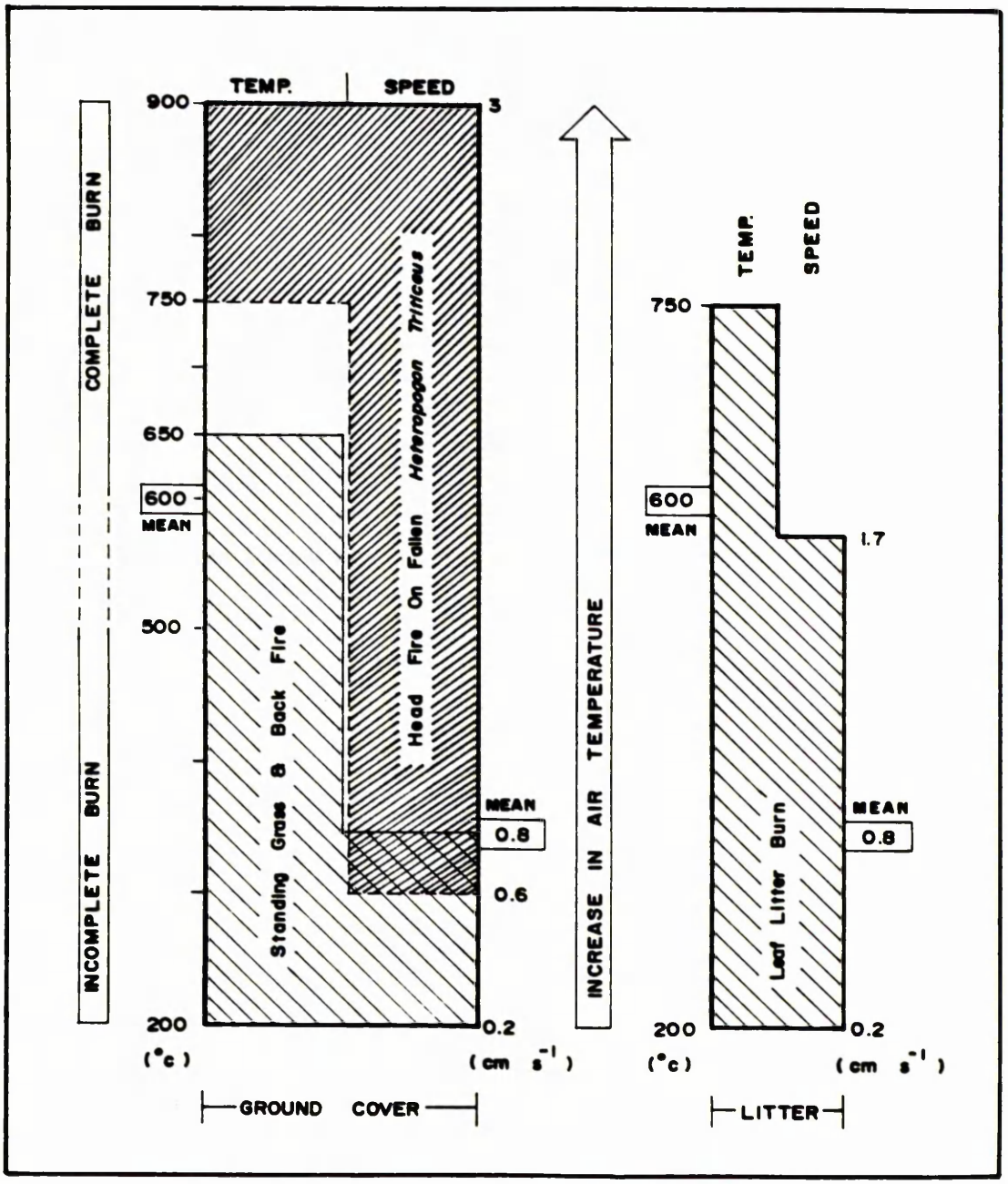


Figure 8.2. Associations of fire temperature, air temperature, speed of fire spread, and grass fuel arrangement for ground cover and leaf litter burns.

Lightning fires may occur occasionally during the early rains of April and May, when thunderstorms are accompanied by little or no rain and occur over dry fuel. But most fires, however, remain human-induced, and these seem to occur whenever the conditions for a burn are favourable. In some years, a short spell of drought can occur in the middle of the rainy season, in July or August, and some fires will burn even then.

8.2.2 Fire behaviour

Fireline intensity ranges from 20->1000 kW m^{-1} throughout the dry season, with flame heights varying from 0.3 m to around 2 m.

Mean maximum temperature at ground-level for both leaf litter and ground cover burns is around 600°C. Mean speed of fire spread is also similar in both fuel types, at 0.8 cm s^{-1}. However, the upper ranges are greater in ground cover burns. Maximum temperatures in leaf litter burns span from 200-700°C, and mean speed from 0.17-1.67 cm s^{-1}; in ground cover burns they range from 200-900°C and 0.17-2.95 cm s^{-1}, the top temperatures and speeds all being in head fires on fallen *Heteropogon triticeus*, ranging from >700-900°C (mean = 819°C), with a rate of spread from 0.55-2.95 cm s^{-1} (mean = 1.67 cm s^{-1}; Fig.8.2).

The duration of absolute maximum temperature at ground-level is usually extremely brief, lasting for less than 5 s, and probably only for 1-2 s. Duration of the highest 50°C bracket is thus regarded as the period of 'maximum' temperature in this study. The mean is <10 s for head fires and almost 1 min for back fires, although too few samples of the latter were studied.

Temperature duration at ground-level of a well-sustained head fire tends to rise and drop suddenly, forming one single sharp peak, with a mean 'maximum' temperature reaching above 600°C lasting for only 5 s in the ground cover burn. Other head fires on heterogeneous fuel distributions, or standing grass clumps, often give an irregular duration pattern, with a few sharp peaks that, together, expose the ground surface to temperatures above 310°C for 15 s. The few back fires on ground cover show a tendency to yield a long duration of maximum temperature, which forms a level-top peak that maintains mean 'maximum' temperature above 270°C for as long as 55 s. Likewise, mean duration of temperature above 50°C is briefest at around 4 min, when the burn is well-sustained under a head fire, compared to 5 min 40 s in other types (Fig.8.3).

Thus, the often fast moving, well-sustained head fire tends to attain the highest temperatures, but with the shortest temperature

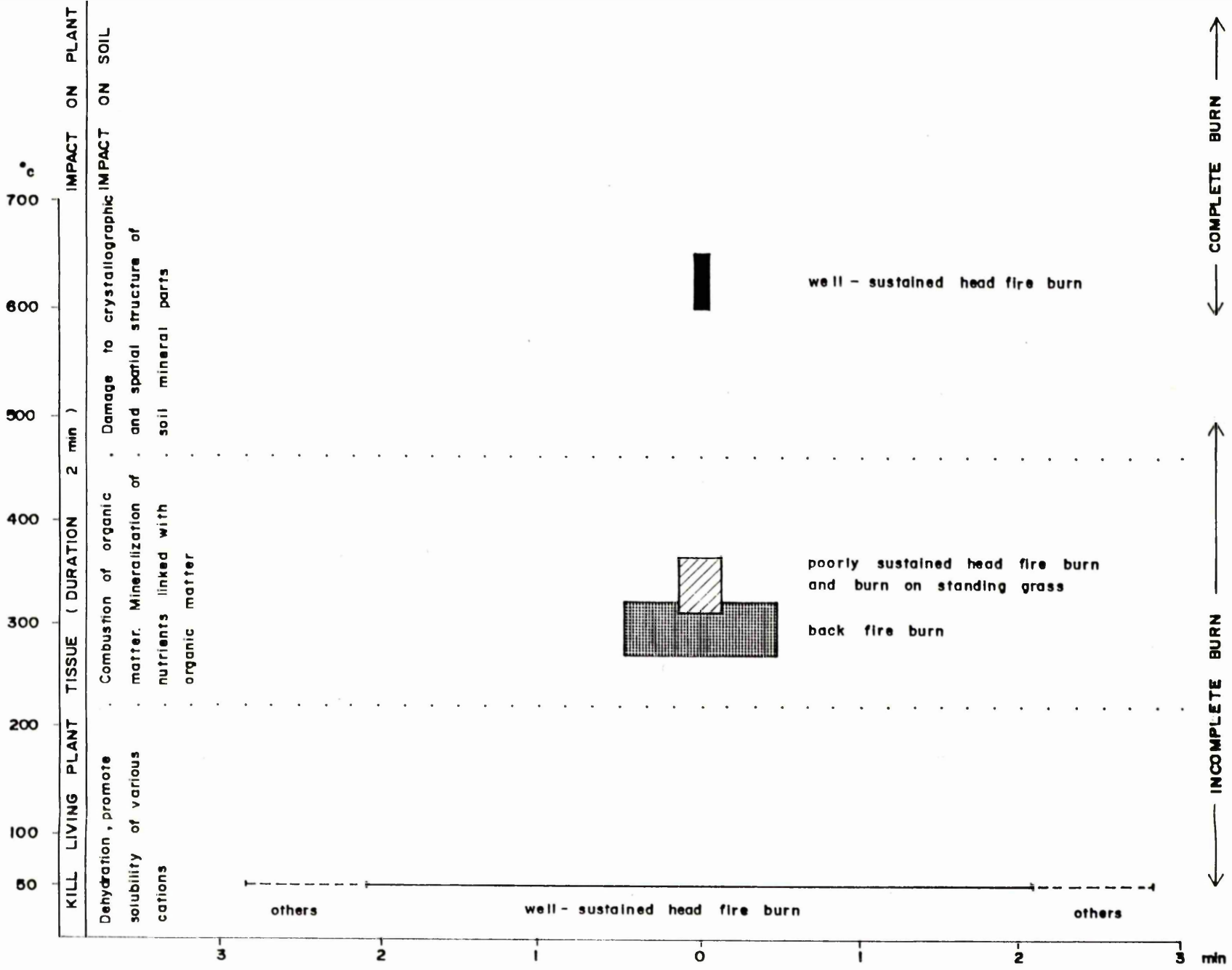


Figure 8.3. Duration of maximum temperature (the highest 50°C bracket) and exposure period to temperatures above 50°C at ground-level in a well-sustained ground cover burn under a head fire, in comparison with other types of ground cover burn. Note the temperature impact on plant tissues and soil characteristics.

durations at ground-level. The pattern is similar in leaf litter burns, where a well-sustained head fire maintains a mean of <10 s duration of temperature above 550°C, and almost 4 min of temperatures above 50°C.

The impact of temperature exposure cannot be evaluated meaningfully without comparative local data on various ecological effects resulting from different levels of heating. Such a study has been made by Giovanni *et al* (1990) on the effects on some Italian soils, although the exposure time taken was not specified. But if their results are used as a rough guideline (see Fig.8.3), then a well-sustained head fire is generally the only kind of burn recorded here that exposes soil for some seconds to a temperature of >460°C, which damages irreversibly the structure of the soil mineral particles, although less impact is expected on sandy soils.

Back fires, on the other hand, have a tendency to yield the longest duration of temperatures between 220-460°C, when combustion of soil organic matter and mineralization of nutrients takes place. Heating up to 220°C is further found to promote solubility of various cations in the soil, but it is not certain if the long duration period of temperatures >50°C of both back fires and some burns on standing grass would actually increase the availability of dissolved nutrients.

At a spatial scale, the highest temperatures attained in the leaf litter burns always occur at ground-level, with a rather consistent temperature of *c.*400°C, while the highest temperatures reached in grass burns tend to occur at 25 cm above the ground, at a mean of 450°C, though ranging widely from <75->750°C. The highest temperatures of all are on fallen *Heteropogon triticeus*, which can attain temperatures of >750°C as high as 1 m above the ground, and up to 125°C at 2 m above the ground. In mixed, partial ground cover/litter burns, the pattern shows characteristics of both fuel types, with temperatures being highest at ground-level and at 25 cm above the ground, with a mean of 300°C. The generally lower temperature in the mixed burn is probably due to the high moisture content of the ground cover component, which probably limits the combustion process of the dry leaf litter.

It was found that it takes a ground-level temperature of >600°C to produce a complete ground cover burn, where grasses and most seedlings are thoroughly charred, the former remaining as short black stumps. In such burns, heights of leaf browning and curling can occur up to 2-10 m above the ground. In contrast, combustion tends to be incomplete at temperatures of <500°C, particularly in burns on standing *Apluda*

Figure 8.4a. Patchy burn on mixed ground cover. (Doi Suthep, Chiang mai province, December 1991). Note the unburned patches in the background.

mutica, where whole semi-green clumps are sometimes left untouched.

The pattern of fire spread in ground cover burns is essentially circular in nature, but two distinct patterns are recognized. The spread observed in highly mixed ground cover in the experimental plots and elsewhere is quite patchy, with many small areas left unburned, particularly when the ground cover is only partially dry. Here, fire sustains largely on flammable fuels as dictated by the wind (Fig.8.4a). When burning conditions are particularly favourable, however, an even burn can sometimes occur, usually late in the fire season.

On the other hand, burns on homogeneous grass fuels spread evenly in a clear circular, or oval pattern, depending on the direction of the prevailing wind and slope (Fig.8.4b). Despite this, patchy burns can occur when the grass cover is only partially dry. This was observed in the very early fire season (Fig.8.4c).

Figure 8.4b. Even burn on homogeneous ground cover. (Khao Nang Rum Research Station, Uthai-thani province, March 1988).

Figure 8.4c. Patchy burn on homogeneous ground cover. (Doi Suthep, Chiang mai province, December 1991).

8.2.3 Fuel and vegetation recovery, and plant phenology

Different times of burn, in the *Dipterocarpus* association, influence greatly the accumulated biomass of leaf litter on the forest floor for the following year. Burns during or after the main period of leaf shedding leave only a thin litter layer, which cannot sustain fire until enough new litter has accumulated, at the end of the next dry season. An unburned area, on the other hand, has a good potential to sustain fire early in the following year, with as much as 95% litter cover at 4 leaves deep accumulated on the ground at the beginning of the dry season.

Burns on the plots in the *Dipterocarpus* 1 stand, on partially dry grass exhibited the lowest temperatures recorded in all the experiments, leaving patches of unburned seedlings and shrubs, and half-burnt grass stumps. It was found that by the end of the following growing season, ground cover percentages here had increased in both the burned and the protected plots, especially in the least disturbed one. There were also signs of an increase in woody species, but the cover area of the grasses decreased slightly in the least disturbed plot, which was neither burned nor heavily trampled by large grazers. Grasses also decreased considerably, by as much as -13%, in the plot burned last, which was fired when the moisture content of all the ground cover was rising and the plants were beginning to flush after dormancy and leaf shedding, using up soil water reserves, before the arrival of the Southwest monsoon. Being hemicryptophytes with buds growing close to the soil surface, the active perennial grasses are probably quite vulnerable to low burning fires.

The rate of recovery was greatest right after disturbances and during early rains, while the undisturbed plot grew noticeably slower than the rest during this period. Seedlings in the burned and trampled plots resumed their former heights, some becoming even taller within one month. Overall, *Dillenia obovata* did particularly well. Although by the end of the year, seedlings were tallest in the unburned plots, this shows that low fireline intensity under this climatic regime does not seriously inhibit seedling regeneration. However, only a long-term experiment would demonstrate the kind of fire regime which maintains the formation structure.

Return visits to the site in December 1990 and January 1992 found the whole stand barely recognizable, except for the dominant trees. Seedlings had grown dense and tall, as fire probably has not occurred every year since the end of the experiment in November 1988. The high

proportion of non-grass growth would have also hindered the occurrence of a hot, extensive fire. By January 1992, very little grass coverage remained, around 10% at the most, resembling much more the monsoon forest, from which it was derived.

Most ground cover species in the *Dipterocarpus* stand seed before the fire season, whereas the canopy trees tend to drop their seeds after fire to germinate quickly on the nutrient-rich soil at the arrival of the early rains. The extent of adaptation of the former strategy to fire is not clear. A proportion of these seeds, particularly in the grasses, are probably buried, and fires may encourage germination and sprouting of some species. Several species flower after fire: indeed some may have been induced, notably the grass *Imperata cylindrica*, which helps to explain why it is so widely successful in cleared and repeatedly burned areas throughout Southeast Asia (Mueller-Dombois & Goldammer 1990).

8.2.4 Discussion of results: the dynamics of fire regimes

In some respects, this study has shown how certain fuel characteristics can produce certain fire behaviour. Three major fuel-fire regimes can be recognized in the dry dipterocarp forests around Khao Nang Rum (Fig.8.5).

1) Mixed ground cover

This tends to occur in moist dry dipterocarp forests with a closed canopy, where there is a high proportion of non-grass ground cover species. Diversity of the grasses is also relatively high, with *Apluda mutica* being significant. Fuel distribution is, therefore, heterogeneous, and moisture content tends to remain high, not falling much below 38%, even in the middle of the dry season in a particularly wet year. Consequently, leaf litter plays an important role in sustaining burns.

In this case, the fire season is short, beginning quite late, in the second half of the mid-dry season, although in a drier year, without such a heavy Northeast monsoon, it could perhaps begin earlier by some three weeks. Burns are largely patchy and incomplete, except sometimes in the late dry season in March, when wind speeds and air temperatures are at their highest.

Fire temperature is generally low on a flat surface, probably not much more than 500° C, often <400°C at ground-level, lasting for 10-35 s. This level of surface heating is likely to do little permanent damage to the soil, and it can be beneficial to plants, provided enough time is

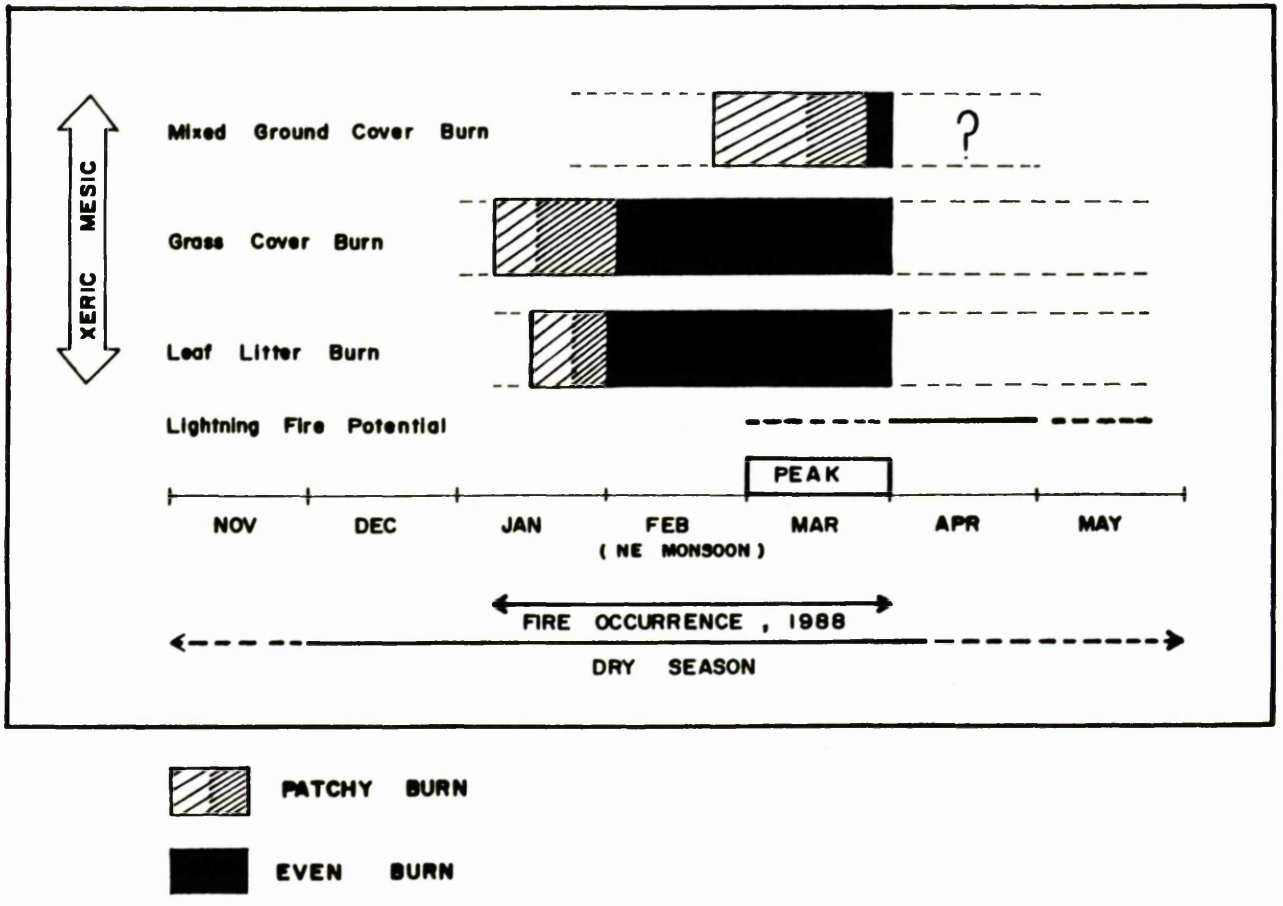


Figure 8.5. Proposed fire regimes for Khao Nang Rum Research Station.

given for organic matter to replenish. At 50 cm above the ground, the temperature does not reach much higher than 125°C. Variations, however, can be great, with a higher fireline intensity occurring in localized patches, where conditions are favourable. An epiphytic orchid on a branch 15 m above the ground was once seen to burn in such a fire, as a gust of wind blew up burning particles (fire spotting).

A high fuel moisture content of >38%, above the level of marginal sustainability, returns sooner than in the open stands, and it is thus likely that the period of burning ends ahead of that in the drier formations. There is still the possibility that a significant cover of leaf litter could sustain a burn, but not without hindrance. However, in April 1988, rain began so early that all fire regimes ceased more or less at the same time.

2) Homogeneous grass cover

A continuous carpet of grass cover of ≥70% usually occurs in the open mesic variant of the *Shorea* association. With few exceptions, the ground cover is normally poor in diversity, often with *Heteropogon triticeus* dominant, sometimes even forming a pure stand. A pure ground stratum of *Chrysopogon orientalis* also occurs in more xeric stands. In this case, leaf litter has a secondary role as fuel, except in gaps.

The fire season is longest in this instance, as the grasses dry early under the open canopy. The very first fires are seen in the beginning of the second week of January, but they are very patchy. The fuel, however, dries fast and fire spread quickly becomes uniformly even, although a burn can still be somewhat incomplete. After the Northeast monsoon in early February, *H.triticeus* is flattened. This then marks the second stage of burning, where fire temperatures are high, even on flat land, from >700-900°C at ground-level under a head fire, lasting briefly for <5 s, and travelling at the fastest speeds recorded, up to almost 3 cm s^{-1}. At 1 m above the ground, temperatures can be as high as >750°C, and still remain at 125°C at 2 m. Such fires could be detrimental to some soil structures, making the soil surface susceptible to accelerated erosion.

Provided there are still unburned areas left, the fuel here has the potential to sustain later fires in April, if the early rains are slight.

3) Leaf litter

This refers to situations in which leaf litter is the primary source of fuel, sometimes covering otherwise bare ground. These conditions obtain in small areas around Khao Nang Rum, in open stands, with heavily eroded, hard and compact soils.

Fire may begin as soon as there is enough leaf cover, which tends to dry much quicker than in the closed stands with a mixed ground cover. In some places, fires begin in mid-January, but they are more common from February onwards. Very early burns can be patchy and limited; otherwise the fire moves evenly in a linear front. Temperature is highest at ground-level, reaching up to almost 750° C, and lasting for <10 s, but it falls sharply below 200° C at 50 cm above the ground.

As the moisture content of the leaf litter readily decreases with a drop in precipitation, a mild drought occurring briefly in the middle of the rainy season can induce litter fires even at this time.

Close observation of mixed ground cover subjected to low temperature burns revealed that patchy, low-burning fire regimes tend to select a heterogeneous community, where woody components are promoted at the expense of grass coverage in the moist, closed forest zone. Although a similar detailed study was not made for a homogeneous grass cover burn, the fire regime there is likely to suppress the establishment of woody growth. A visit to the site in January 1992 found that the open *Shorea* association at 460 m.a.s.l. next to the research station had lost much of its ground cover. Repeated late season burning in March had also eroded much of the top soil, and grass growth is no longer as dense, being sparse, at times exposing bare ground surfaces. If this trend continues, it is possible that leaf litter will become increasingly more important as a source of fuel, which will then shift the basic fire regime.

While herbivory and exceptional climatic events can modify fuel regimes, thus having a synergistic effect on the fire regime itself, humans can modify both fire and fuel directly. Most apparent is the shift from the presumed 'natural' fire regime caused by dry thunder, which occurred mainly in the very late dry season in April, and at a lower frequency, to anthropogenic fire regimes, occurring frequently and extensively, more or less whenever fire can be sustained. At the same time, burned areas are expanded through tree-cutting, subsequently opening up the canopy and changing the fuel regime.

8.3 Thesis contribution: theoretical

8.3.1 Comparison of data

It was found that not only can different timings of burn sometimes create different mosaics of vegetation and fuel load, but the fuels can also dictate the times of burn. This is particularly clear in the case of leaf litter fuel, where the temporal and spatial patterns in its biomass are much influenced by the times of previous burns. In turn, the change in litter biomass may shift the potential time for burns in the following year, e.g. from an early burn in one year to a late burn in the next, or an early burn in an area where there was no burn in the previous year. Changing patterns of fuel biomass may, therefore, rotate fire timings and/or fire frequency in some savanna forest stands.

In the regional context, this thesis is the first attempt to gain some insight into the seasonal patterns of fuel-fire relationships, and, to a limited extent, their dynamics in the past and the present. It is one of the few works (e.g. Stott 1986, Rabinowitz 1990b) which recognize the importance of understanding *different* fire behaviours (as opposed to a mere 'fire'), and their varying impact on the ecosystem, although data collected for this particular purpose is limited through unexpected problems in the field. For the first time, an enquiry is made into the possibility of natural fire regimes, which has almost always been considered irrelevant in Thailand.

The lightning fire regime described here corresponds well with those occurring in the savanna regions elsewhere in the world, particularly during the late dry season-early wet season (e.g. Braithwaite & Estberg 1985, Frost & Robertson 1987). Maximum moisture content of grass to sustain fire is also comparable, for example, to Walker and Tothill's (1981) findings in the Northern Territory, Australia, where a grass moisture content of >35% usually resulted in fire extinction. The general positive correlation between air temperature and fire temperature is another relationship commonly found elsewhere (e.g. Trollope 1984b).

Trollope (1984b) has also noticed the importance of fuel compaction in relation to optimal combustion, but the detail of this variable and its seasonal pattern has not really been studied. This thesis has shown how patterns of grass fuel arrangement can be phenomenally seasonal in some important species, and how this has a very significant impact on the fire regime.

Ranging from 20->1000 kW m^{-1}, fireline intensity in this study is comparatively lower than in South African savannas, where it can range

from <160-5993 kW m^{-1} (van Wilgen & Willis 1988, Trollope 1978). However, fire temperature measurements obtained in this study are comparable to other work done in the region (Stott 1986) and on other continents (e.g. Hopkins 1965, Pitot & Masson 1951, Rains 1963, Coutinho 1982, see also Frost & Robertson 1987), where maximum temperature at ground-level can range from <70->800°C, with back fires rarely rising >400°C. The highest mean temperatures for ground cover burns occur at, or just above the ground surface, usually from 0-50 cm high, but sometimes up to 100 cm (Stott 1986). The duration of maximum temperature at ground-level can range from a few minutes to a few seconds, and duration of temperature above 50° C or 60° C at ground-level ranges from around 1->4 min.

The pattern of recovery in this study has a tendency to reflect the trend observed in many moist woodlands in Africa, where burns on partially dry grass inhibits its full recovery, while low fireline intensities tend to promote woody species. However, in both Africa and Australia, low fireline intensity, producing patchy burns, is considered to be a characteristic of early burns on partially dry grass, under a relatively cool climate (e.g.Hopkins 1965, Braithwaite & Estberg 1985). Characteristics of dry season fire at different timings in Khao Nang Rum Research Station cannot yet be established fully without more burns being monitored throughout the season. However, this study shows that both low and high temperature burns can occur at any time in the fire season, depending on the conditions for the burn in each case.

The point to be stressed here is that while it is certainly valid to define burn characteristics according to seasonal timings, the terms 'early', 'mid-season' and 'late' burn should be related to a specific formation and locality, because each has different fire seasons with distinctive characteristics, particularly in terms of micro-climate and species composition, even when exposed to the same overall dry season regime as the neighbouring formations. Too often, the terms 'dry season' and 'fire season' are not being distinguished satisfactorily in texts on forest fires.

8.3.2 Methodology

The combined use of an infra-red pyrometer, 'thermocolor' pyrometers, and Byram's (1959) evaluation of frontal fireline intensity from a series of flame heights can give a very full description of both the temporal and spatial pattern of fire behaviour with extensive sampling. Each methodology describes an aspect of fire behaviour which

cannot be covered by the others. Indeed, the overall 'intensity' of a fire is a combined impact of both temperature duration and intensity at the fireline. All too often, the widely-used term 'fire intensity' is left unspecified.

The use of the infra-red pyrometer to measure temperature at ground-level has proved to be both effective and convenient. Graphs showing the continuous duration and pattern of savanna fire temperatures are thus demonstrated for the first time. A compact graph printer could be connected to the pyrometer in a future study. Reliable measurement of temperature duration at higher levels above the ground could be done by clamping the pyrometer to a pole, making sure it is set on the level, so that it does not aim downward to a point further on the ground.

Measurement of spatial patterns of temperature should also be developed to show horizontal distribution at close intervals. Lateral temperature radiation is important in the understanding of the survival or adaptive pattern of patch ecology, which will give an insight into some aspects of the maintainance processes of savanna ecosystems.

Accurate estimation of flame height, however, can be difficult, as it varies greatly, even within seconds. Estimation made against marked metal stakes, as was done in this study, can be useful, but the method can be much improved by taking a series of photographs at a regular interval, with flames set against a series of grid lines of closely-marked stakes, perhaps at every 10 cm in height. Subsequent estimation made from a still visual record will be a lot more accurate.

Using a series of marked metal discs to plot patterns of fire spread at a regular interval, as developed by Mather (1978a), is effective and easy to do. This could be coupled with a rough map of unburned patches, if they occur, in order to give the most meaningful picture of fire patterns.

8.3.3 Suggestions for further research

There is much potential for further research on fire timing. Both long term control experiment, and extensive monitoring of fire behaviour and fire occurrence in different areas, are very much needed. Even when no pyrometer is available, a simple estimation of fireline intensity can give a very satisfactory measurement. Patchiness and extensiveness of burns could also be estimated quickly, particularly with the use of a light air craft for low-level remote sensing. Fire monitoring, however, needs good team work. The lack of personnel has

always been a problem in forestry and wildlife research stations in Thailand.

Further enquiry ought to be made into the probable spatial occurrence of lightning fires, in terms of both regions and altitude. It would help towards a search for the ancient fire dynamic, which is essential for developing an understanding of savanna evolution in the area. Such lines of enquiry are currently being developed by Ms Pat Wolseley and Dr.Bergoña Aguirre-Hudson of the Natural History Museum, London, using lichen communities as an indicator of forest antiquity and fire regimes (Wolseley & Aguirre-Hudson 1991).

There is also an urgent need to study the impact of fire timing on animal populations and the use by wildlife of different habitats throughout the fire season, in order to help managers of conservation areas to plan an appropriate fire management policy for each location. The study of fire effects on insect populations is also vital, and in particular on the termites, which are responsible for as much as 20% of the carbon mineralization in other tropical savannas (Holt & Coventry 1990). Termite populations could be diminished significantly with over burning, for fire threatens their niche as decomposer of carbon compounds.

The effects of fire timing on the moisture reserves of rejuvenating vegetation, as well as the impact from grazers, all require study. Indeed, the list could go on. Above all, it is important to recognize and to implement the use of fire timing and placement as a neccessary tool for "the prevention of destructive wildfires and the conservation of the biological diversity and attractiveness of our open landscapes in fire-induced plant communities, ecotones and corridors" (Naveh 1990:1).

8.4 Thesis contribution: fire management in Thailand

The findings of this study emphasize, above all, the importance of local factors in determining the specific fire ecology of an area. It seems all too obvious, but this concept is still not recognized by the Forest Fire Control Unit (FFCU) of the Thai Royal Forest Department (RFD). Not only is the central state policy of complete fire protection ecologically unsound and impractical (see Section 1.4, pp.40-41), it is also inappropriate in many other ways. The fact that lighting forest fires is forbidden by the authorities and is a criminal act punishable by not more than a 20,000 baht fine and/or not more than 5 years imprisonment (Chaipet 1980), makes local people reluctant to discuss

their own practices with outsiders. This was experienced both by myself, and by Maneeratana and Mather (1978), while conducting questionnaires on the causes and local management of forest fires.

Although seemingly receptive to discussion, few people ever admitted to lighting fires themselves. The act was always blamed on others. The Karen, an indigenous ethnic minority known for their conservation-minded traditions (Thiraprasarn, pers.comm.), blamed the Thais. The Thais then blamed the Laos migrants from the northeastern region, or else they blamed children. Above all, most blamed Forestry officials themselves, as being one of the chief sources responsible for causing fire (see Table 1.3). Such reactions will soon lead to the loss of any knowledge of traditional fire management, which will not then be passed down to the next generation because first, it cannot be an open act, and secondly, forested areas are rapidly being depleted, and a high number of the younger generation are seeking their livelihoods elsewhere. An anthropological study involving participatory observation is urgently needed in this respect.

Furthermore, personal observation has found that top-down attempts of state control management can sometimes diminish the local sense of responsibility towards resource management. Above all, it creates land-use conflict between forestry officials and villagers living in forest reserves. Indeed, many fires are deliberately set to destroy young plantations to undermine afforestation efforts by the Royal Forest Department (RFD) or logging companies. The situation is such that while the Royal Forest Department tries to conserve and manage forested land according to national policy, which is subject to the political climate and changing government personalities, the villagers, on the other hand, are not recognized as land managers with shared responsibility. Unlike many local land managers in the United States and Australia, who have buyer power to select management software packages, Thai villagers have no bargaining power either in economic or legal terms. They are constantly at the receiving end of management policy.

The land-rights problems in forest reserves have been magnified since the mid-1970s (Hafner 1990). Although policy regarding the issue changes constantly, in practice, it has always remained an essentially top-down, expert-planning approach, even after the prominent rise of mass environmental movements in the mid-1980s (e.g. Hirsch & Lohmann 1989), and despite the 1985 National Forest Policy which was aimed towards public participation at all levels (National Forest Policy 1985).

Grass roots movements have been further undermined since the February 1991 military coup d' ètat. Despite the growing darkness over Thailand's political situation, however, there are increasing numbers of forestry officials who genuinely appreciate the value of local knowledge and experience, and who recognize the local rights and need to share the country's natural resources.

Yet, while some individuals in the Royal Forest Department are working towards collaboration, the Forest Fire Control Unit (FFCU) is moving in the opposite direction. It is crucial that the FFCU should cooperate with other divisions, such as the National Forest Land Management Division (NFLMD), to build local fire management schemes into the programmes where villagers participate in every step of planning and implementation, including choosing fire-protected areas and determining objectives and zones for fire prescription, using fire timing and placement as management tool.

For example, in Omgoi Wildlife Sanctuary, Northwest Thailand, grassland is indiscriminately burned to promote grazing for domestic cattle. This has resulted in grassland encroachment into ancient evergreen forests. If the local communities can be allowed to manage the rangeland resource in designated zones, fire could perhaps be kept out more effectively from the sensitive evergreen forests and watershed areas. The present illegal status of *all* wildland burning encourages 'light-and-run' uncontrolled burning, which often develops into undesirable destructive fire. As shown in this thesis, locally appropriate prescription of fire timings and placements can create a mosaic of vegetation and fuel loads, which helps to deter extensive wildfire in the late dry season. Early burning, which promotes woody growth, can be used to protect sensitive ecotones.

From the brief interview trip with villagers along the Huai Kha Khaeng Wildlife Sanctuary border in December 1987, it was apparent that 8 out of 19 villagers from 17 villages had their own ideas for fire management other than complete fire protection, prescribed burning by forestry officials, or a 'let-burn' policy. While most could not yet give a precise management scheme, they agreed that some fires are needed in the dry dipterocarp forest, but they must somehow be controlled. One respondent suggested a collaboration scheme among villages in the catchment area, although he was pessimistic about the local rifts within the community. Likewise, 56% of 136 educated Thai residents involved in conservation in 1987 saw that forest fire can be both good and bad, and

91% felt some measure of fire prescription is needed[11], although the general attitude, understandably, was to regard all fires as largely detrimental, given the extensive uncontrolled burning witnessed today.

Funded by USAID/DTEC's MANRES Project[12], the National Economic and Social Development Board (NESDB) has recently contracted the Faculty of Forestry at Kasetsart University to carry out a study entitled "Forest fire and its effects on forest systems in Thailand." The document made recommendations towards natural resource planning in regard to forest fire management, having been allowed a mere 3 months for completion. Although it concludes sensibly that the poor ecological consequences of uncontrolled forest fire far outweigh its benefits, it emphasizes too much on irrelevent economic losses. For example, burned grass and litter layers are regarded as a loss in the potential harvest of natural fertilizer !

More efficient forest fire prevention and control was proposed. Among the list of practical recommendations is the proposal for the urgent recruitment of a "community organizer position to coordinate activities between government officers and villagers for solving forest fire problem" (Kettupraneet *et al* 1991:12). Such activities, however, put the emphasis on one-way public relations to re-educate villagers towards a 'better understanding' of forest fires, *as being perceived by the officials themselves.*

While there is little doubt that strong circumstantial evidence does indeed point towards the detrimental impact of present-day excessive burning, which occurs mainly during the mid and late dry season, particularly in sensitive watershed and evergreen forest zones, it is clear that policy formers must at the same time examine their own bias. This springs essentially from the standpoint of a traditional forestry training, where forests are valued largely by the price of the timber they produce. Often, what is regarded as 'bad', can be an entirely subjective view point, for it could be considered desirable by others. Open forests, for example, can support certain undergrowth not available or abundant in closed formations, on which the local subsistence and small cash economy depends. Such conflict demands better communication and respect for the other parties involved than is now offered by the government.

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[11] Results from Social Survey I (see Section 4.6).

[12] DTEC : Department of Technical and Economic Cooperation.
MANRES : Management of Natural Resources.

The Forest Fire Control Unit would benefit much by changing its policy and attitude towards local participation (as opposed to public relations). It is simply more practical in terms of the manpower and distribution of responsibility required in fire management and control. Their access to central state resources should be employed in those areas where powerful technology and a network between various agencies are required. Satellite monitoring of fire occurrence and the emission of 'greenhouse gases' are two examples.

Although much can be achieved through changing political and administrative structures, a lot more research on forest fire ecology is also needed. While there is still a lack of data, fire management needs necessarily to be based on historical experiences and intuition (Sneeuwjagt 1989). Additional information obtained, however, can later be integrated into the management scheme, such as new details on the variables governing fire timing.

It is hoped that this thesis will contribute a little to our better understanding of forest fires in Thailand, and to their better management in the future.

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GLOSSARY

Ignitability: the capacity for a given fuel to be ignited.

Sustainability: the capacity for a given fuel to sustain fire.

(Frontal) fireline intensity: the rate of energy output per unit length of fire front, usually expressed as kW m^{-1}.

Intensity (of fire): a general term referring to total energy output of a fire throughout its duration period at a given site. It is used only in general discussion where no specific data on fireline intensity and duration of temperature is available.

Fire regime: the entity comprising all fire characteristics, which include the spatial pattern of fire temperatures, temperature duration, fire intensity, the speed and pattern of fire spread, and frequency of occurrence.

Head fire: a fire burning with the wind direction.

Back fire: a fire burning against the wind direction.

Flanking fire: a fire burning at an angle to the wind direction.

APPENDIX I

List of ground cover species and their occurrences on the experimental plots (A, B, C, D) in the *Dipterocarpus* 1 stand, 1987-1988.

GROUND COVER SPECIES	FAMILY	TYPE	OCCURRENCES		
			Oct 87	Jan 88	Nov 88
GRASSES					
Apluda mutica L.	GRAMINEAE	G	ABCD	ABCD	ABCD
Coelorachis mollicoma (Hance.) Bor.	GRAMINEAE	G	ABCD	ABCD	ABC
Eulalia speciosa (Debeaux.) O.Kitze.	GRAMINEAE	G	A	A	ABC
Heteropogon triticeus (R.Br.) Stapf.ex Craib	GRAMINEAE	G	ABCD	ABCD	ABCD
Imperata cylindrica (L.) Beauv.	GRAMINEAE	G	ABCD	ABC	ABC
Panicum auritum Presl.er Nees.	GRAMINEAE	G	BC	BC	BCD
Saccolepis sp.	GRAMINEAE	G			A
Setaria pallide-fusca (Schumach.) Stapf.	GRAMINEAE	G	ABCD	ABC	ABCD
Sorghum nitidum Pers.	GRAMINEAE	G	ABCD	ABCD	ABCD
unidentified sp.1	GRAMINEAE	G	D		
SEDGES			Oct 87	Jan 88	Nov 88
Carex speciosa Ktze.	CYPERACEAE	H	ABCD	ABCD	ABCD
Cyperus cyperoides Ktze.	CYPERACEAE	H	ACD		AB
Scleria psilorrirhiza C.B.Clarke.	CYPERACEAE	H	ABCD		AD
GEOPHYTES			Oct 87	Jan 88	Nov 88
Costus speciosus Smith	COSTACEAE	H	AC		AC
Chlorophytum sp.	LILIACEAE	H	AD	D	D
Curcuma parviflora Wall.	ZINGIBERACEAE	H			ABCD
Globba leucantha Miq.	ZINGIBERACEAE	H	ABCD		ABCD
Globba obscura K.Lar.	ZINGIBERACEAE	H			ABCD
Kaempferia pulchra Ridl.	ZINGIBERACEAE	H	ACD		AC
Zingiber zerumbet Smith	ZINGIBERACEAE	H	ABC		AB
unidentified sp.1		H			D
unidentified sp.2		H			B
Habenaria linguella Lindl.	ORCHIDACEAE	O	(August 88, AC)		
Tropidia sp.	ORCHIDACEAE	O		A	A
OTHER HERBACEOUS SPECIES			Oct 87	Jan 88	Nov 88
Andrographis sp.	ACANTHACEAE	H			CD
Cyanotis barbata D.Don.	COMMELINACEAE	H	ABCD	C	AD
Murdannia sp.	COMMELINACEAE	H	ABC		AD
Elephantopus scaber L.	COMPOSITAE	H	BCD		D
Eupatorium odoratum L.	COMPOSITAE	H	BCD	CD	BCD
Laggera sp.	COMPOSITAE	H			D
Phyllanthus amarus Schum.ex Th.Kongl.	EUPHORBIACEAE	H	ABCD	C	ABCD
Leucas sp.	LABIATAE	H	A	A	A
Sonerila sp.	MELASTOMATACEAE	H			D
Crotalaria sp.1	PAPILIONACEAE	H			B
Crotalaria sp.2	PAPILIONACEAE	H			ABD
Desmodium alatum D.C.	PAPILIONACEAE	H			CD
Desmodium motorium (Houtt.) Merr.	PAPILIONACEAE	H	ABC	ABC	ABC
Sophora sp.	PAPILIONACEAE	H			B
Acanthac sp.	ROSTRELLURARIA	H			BD
Hedyotis sp.	RUBIACEAE	H	C	ABCD	ABC
Knoxia corymbosa Willd.	RUBIACEAE	H			CD
Dioscorea sp.	DIOSCOREACEAE	HC			C
Scindapsus siamensis Engl.	DIOSCOREACEAE	HC		D	C

Appendix I, continued.

WOODY CLIMBERS			Oct 87	Jan 88	Nov 88
Toxocarpus sp.	ASCLEPIADACEAE	C	ABCD	ABCD	ABCD
Abrus sp.	PAPILIONACEAE	C	A		A
Dalbergia volubilis Roxb.	PAPILIONACEAE	C	ACD	ABC	ABC
Spatholobus parviflorus Ktze.	PAPILIONACEAE	C	ABCD	ABCD	ABCD
Paederia sp.	RUBIACEAE	C	B	B	BC
Smilax perfoliata Lour.	SMILACACEAE	C			
Thunbergia fragrans Roxb.	THUNBERGIACEAE	C	A	C	ACD
Cissus sp.	VITIDACEAE	C	ABD		AB
unidentified sp.1		C			B
unidentified sp.2		C		B	

SHRUBS			Oct 87	Jan 88	Nov 88
Chloranthus officinalis Bl.	CHLORANTHACEAE	ExUS	AB	ABCD	B
Barleria cristata L.	ACANTHACEAE	US	CD	ACD	ACD
Pavonia rigida Hochr.	MALVACEAE	US	ABCD	ABCD	ABCD
Sida sp.?	MALVACEAE	US		A	
Polyalthia debilis Finet.ex Gagnep.	ANNONACEAE	S	ABCD	ABCD	ABCD
Bauhinia sp.	CAESALPINIACEAE	S	ACD	ACD	ACD
Euonymus sp.	CELASTRACEAE	S			BC
Pluchea polygonata (D.C.) Gagnep.	COMPOSITAE	S	ABCD	ABCD	ABCD
Erythroxylum cambodianum Pierre	ERYTHROXYLACEAE	S	ABCD	ABCD	ABCD
Sauropus sp.	EUPHORBIACEAE	S	C		C
Leea indica Merr.	LEEACEAE	S	BCD	BCD	BCD
Ardisia crenata Roxb.	MYRSINACEAE	S	ABCD	ABCD	ABCD
Flemingia sp.1	PAPILIONACEAE	S	ABCD	ABCD	ABCD
Flemingia sp.2	PAPILIONACEAE	S			B
Moghania macrophylla Ktze.	PAPILIONACEAE	S	BC	BCD	C
unidentified sp.3	PAPILIONACEAE	S	B		
Pavetta indica L.	RUBIACEAE	S	AD	ACD	A
Helicteres sp.	STERCULIACEAE	S	ABCD	ABCD	ABCD
Grewia abutilifolia Vent.ex Juss.	TILIACEAE	S	BCD	ABCD	CD
Grewia sp.	TILIACEAE	S			CD
unidentified sp.1		S	ACD	CD	CD
unidentified sp.2		S	D		

TREE/SRUB-TREE SEEDLINGS			Oct 87	Jan 88	Nov 88
Diospyros ferrea (Willd.) Bakh.	EBENACEAE	S/ST	BD	BD	BD
Ochna integerrima Merr.	OCHNACEAE	S/ST	AB	AB	B
Randia parvula Ridl.	RUBIACEAE	S/ST	ABCD	ABCD	ABCD
Antidesma ghaesembilla Gaertn.	STILAGINACEAE	S/ST	AB		AD
Diospyros castanea Fletch.	EBENACEAE	ST	ABCD	ABCD	ABCD
Aporusa villosa Baill.	EUPHORBIACEAE	ST	AB	B	BCD
Helicia nilagirica Bedd.	PROTEACEAE	ST	BD		
Antidesma bunius Spreng.	STILAGINACEAE	ST	D		BD
Anneslea fragrans Wall.	THEACEAE	ST	C	C	C
Grewia disperma Rottler	TILIACEAE	ST	ABC		ACD
unidentified sp.1		ST	B		
unidentified sp.2		ST		BD	BC
unidentified sp.3		ST	BD	BD	D
Buchanania latifolia Roxb.	ANACARDIACEAE	T	ABD	ABD	AB
Mangifera sp.	ANACARDIACEAE	T	D	D	D
Spondias pinnata Kurz	ANACARDIACEAE	T	BC		BC

Appendix I, continued.

Stereospermum neuranthum Kurz	BIGNONIACEAE	T	D	D	D
Protium serratum Engl.	BURSERACEAE	T	ACD	AC	AC
Cassia fistula L.	CAESALPINIACEAE	T	BC	BC	B
Siphonodon celastrineus Griff.	CELASTRACEAE	T	B		
Terminalia alata Heyne.	COMBRETACEAE	T	ABD	ABD	AD
Terminalia bellerica Roxb.	COMBRETACEAE	T	C	C	
Dillenia obovata (Bl.) Hoogl.	DILLENIACEAE	T	ABCD	ABCD	ABCD
Dipterocarpus tuberculatus Roxb.	DIPTEROCARPECEAE	T	ACD	ACD	AD
Shorea obtusa Wall.	DIPTEROCARPECEAE	T	ABCD	ABCD	ABCD
Shorea siamensis Miq.	DIPTEROCARPECEAE	T	B	B	C
Diospyros ehretioides Wall.ex G.Don.	EBENACEAE	T	ABC	ABC	ABC
Glochidion sp.	EUPHORBIACEAE	T	ABCD	ABCD	ABCD
Phyllanthus emblica L.	EUPHORBIACEAE	T	ABCD	ABCD	ABCD
Lithocarpus polystachyus Rend.	FAGACEAE	T	C		
Lithocarpus sp.	FAGACEAE	T	BC	AC	ABD
Quercus brandisiana Kurz	FAGACEAE	T	ABC	ABC	BC
Cratoxylum pruniflorum Kurz	GUITTIFERAE	T	ABCD	ABCD	ABCD
Beilschmiedia sp.	LAURACEAE	T	B		B
Phoebe paniculata Nees.	LAURACEAE	T	B	B	
Lagerstroemia sp.	LYTHRACEAE	T	AC	AC	AC
Horsfieldia sp.	MYRISTICACEAE	T	C	C	AC
Eugenia cumini (L.) Druce	MYRTACEAE	T	A	A	A
Dalbergia oliveri Gamble	PAPILIONACEAE	T	ACD		
Dalbergia sp.	PAPILIONACEAE	T	ABCD	ABCD	ABCD
Pterocarpus macrocarpus Kurz	PAPILIONACEAE	T	ABCD	ABCD	ABCD
Gardenia sootepensis Hutch.	RUBIACEAE	T	C	C	
Schleichera oleosa (Lour.) Oken.	SAPINDACEAE	T	ABCD	ABCD	BC
Pterocymbium javanicum R.Br.	STERCULICEAE	T	BD		
Celtis tetranda Roxb.	ULMACEAE	T	ABCD	ABCD	ABCD
Vitex canescens Kurz	VERBENACEAE	T	D		
Vitex limonifolia Wall.	VERBENACEAE	T	ABD	ABD	ABCD
Vitex sp.	VERBENACEAE	T			B
unidentified sp.1		T	B		

NOTE

Oct 87 : species count during 29 October - 3 November 1987

Jan 88 : species count during 27 January - 2 February 1988

Nov 88 : species count during 27-28 November 1988

ABCD : represents occurrences in stated plots

PLANT TYPES (after Smitinand, 1980)

G = grass

O = orchid

H = Herbaceous species

HC = herbaceous climber

C = woody climber

ExUS = exogeneous undershrub

US = undershrub

S = shrub

ST = shrub-tree (seedling)

T = tree (seedling)